An Acoustic and Perceptual Study of Vowel Formant Trajectories in American English

RLE Technical Report No. 563

Caroline B. Huang

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by

Caroline B. Huang

Abstract

The present study extends the existing body of work on vowels in several ways. Three factors – consonantal context, lexical stress, and speech style – which have been previously shown to affect the acoustics of vowels separately, are examined and compared on the same database. In the past, isolated vowels, vowels from nonsense words, and vowels from words in carrier phrases have been widely studied. In the present study, vowels are taken from more natural speech styles, including a read story and spontaneous speech. In addition to describing the vowels in terms of their midpoint formant frequencies, as has often been done previously, the present study attempts to characterize the vowels in terms of some aspects of their formant trajectories. Finally, the vowels' acoustic properties are related to the ability of human listeners to identify the vowels.

The database consisted of the vowels /i/, /ɪ/, /e/, /ɛ/, and /ʌ/, labelled phonemically. Approximately 850 vowel tokens were collected from one speaker, and 200 tokens were collected from each of three additional speakers. The consonant contexts studied were /b/, /d/, /g/, /w/, /r/, and /l/. Only primary and secondary levels of lexical stress were considered. Schwa vowels were excluded from the database. The speech styles considered were nonsense words in a carrier phrase, real words in a carrier phrase, a read story, and spontaneous speech. The spontaneous speech was elicited by interrupting the speakers at intervals while they were reading the story and asking them to retell the story.

Consonant context was found to affect the vowel midpoints more than lexical stress and speech style in the present study. The direction and magnitude of the formant frequency shifts found in the present study were consistent with findings of previous studies. The liquid and glide contexts, /w/, /r/, and /l/, lowered the F2 frequency of front vowels, especially lax front vowels, on the order of one Bark relative to the F2 frequencies when the same vowels are adjacent to stop consonants. Shifts for F1 tended to be smaller than shifts in F2, even on a Bark scale, and were less consistent across speakers.

The formant frequency midpoints and durations of vowels carrying primary stress were shown to differ only slightly on average from the those of vowels carrying secondary stress, if the other factors were held constant. Vowels in continuous read speech also differed only slightly on average from vowels in spontaneous speech.

Data on some aspects of the formant trajectories have been compiled. Variation in characteristics of the formant trajectories seems to have perceptual consequences. For

example, the F2 of 65% of the /e/ tokens for one of the speakers of the database has a late rise signifying the presence of a /y/ offglide, which is typical for /e/ in American English. The other tokens do not have the characteristic offglide, and they tend to be misidentified as lax vowels by listeners.

In general, the data show that variations in vowel midpoint formant frequencies, durations, and trajectory shapes are correlated with the perception of the vowel by human listeners. For example, /ɛ/ tokens which have F1-F2 midpoint values typical of /ʌ/ tend to be identified as /ʌ/, and /e/ tokens which are short and lack a /y/ offglide, typical characteristics of lax vowels, tend to be misidentified as lax vowels.

Aspects of the trajectories which are important for characterizing the vowel were sought. The trajectory was used to derive a representation of the vowel by one point per formant, a modified "midpoint." Performance by a Gaussian classifier was the criterion used to evaluate different representations of the vowels. If the effect of perceptual overshoot for F2 and perceptual averaging for F1 was simulated, and the resulting modified midpoint was used as input for the classifier, performance was somewhat better than if the durational midpoints were used as input. However, the best performance was achieved if the raw data – the quarter-point, midpoint, and three-quarter point of the trajectory and the duration – were used as input to the classifier. The improved performance with the raw data over the modified midpoints shows that not all of the significant aspects of the trajectory have been captured in a one-point representation. It may be that a new one-point representation could be found which would result in as high performance as the raw data. Alternatively, it may be necessary to use more than a modified midpoint to fully characterize a vowel.

Of all the representations used as input to the statistical classifier, the raw data also result in the best agreement of the classifier with the human performance. If the classifier is also allowed to train and test on vowels in stop and liquid-glide contexts separately, agreement with the listeners' responses (and performance in the conventional sense, i.e., agreement with the transcriber's phonemic labels) improves further. The improvement due to separating the contexts suggests that humans perform vowel-identification in a context-dependent manner.

Thesis Supervisor: Kenneth N. Stevens
Title: LeBel Professor of Electrical Engineering

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Chapter 1

Introduction

1.1 Acoustics and Perception of Vowels: Questions

Speech sounds exhibit much variability, yet humans are able to extract enough information to communicate through speech. The relationships among the acoustic properties, the perception, and the phonemic identity of a speech sound are still not completely understood. These relationships have long been sought both to increase our scientific knowledge about the speech mechanism and for practical applications, such as speech recognition and speech synthesis by machine. The present study continues the effort to clarify the relationships for one class of speech sounds, the monophthongal vowels.

For the present study, it is assumed that vowel production begins with an intended vowel phoneme. Associated with each vowel phoneme is a set of characteristic acoustic properties, perhaps context-dependent, which a speaker tries to produce when uttering that vowel. Because of constraints on the articulators and, possibly, context-sensitive variations in the speaker's intention, variability occurs in production. Realizations of a vowel phoneme occupy a region in the space of parameters chosen to describe the vowel's acoustic properties. An example of such a space is the familiar plot of the first and second formant frequencies (F1 and F2) of the vowel at some point in time. The listener uses the vowel properties and knowledge of the context and the lexicon to distinguish the vowel from other vowels. It is assumed that vowel realizations well within their own regions will be easier to identify than vowel realizations which are close to the region of a different intended vowel. Where regions overlap, vowels are assumed to be particularly difficult to identify.

The present study considers the following questions:

- What is the relative contribution of some factors which cause vowel variability, and how do they interact? The specific factors chosen for this study are consonantal context, lexical stress, and speech style.

- Which aspects of the vowel formant trajectories are important for describing vowel variability? The vowel formant frequencies at one point in time have often been used in previous studies. The present study aims to gain further information about a vowel from other aspects of its formant trajectories.

- Much previous work has been done investigating vowel variability in nonsense words, isolated real words and words in carrier phrases (see, for example, Stevens and House, 1963; Stevens et al., 1966; Lehiste, 1962; Delattre, 1969; Öhman, 1966; Magen, 1989; Manuel and Krakow, 1984). To what extent are the results similar for vowels from real words in connected speech?

- How well can listeners identify vowels when the vowels are presented without any lexical information? Which confusions do listeners make, and can the confusions be explained in terms of properties of the vowel's formant trajectories?

This study consists of an acoustic analysis of vowels taken from connected, meaningful speech and a set of tests examining the perception of the same vowels. In the next section, related previous work will be discussed. Then, the experimental approach of the present study will be described in more detail.

1.2 Previous Studies

Much work has been done investigating the acoustic characteristics of vowels and the perception of vowels. In the following, a representative sample of the previous work will be briefly described. Areas where further work must be done will be pointed out. Unless otherwise specified, the described results were found studying American or Canadian English.

1.2.1 Factors Found to Influence Vowel Formant Frequencies in Isolated Words; The Need for Studies on Connected Speech

Previous acoustic studies have shown that consonantal context, lexical stress, and speech style exert a strong influence on vowel formant trajectories. Several investigators have found consonantal context, the consonant immediately before the vowel and the consonant immediately after the vowel, to affect the vowel formant frequencies systematically. Stevens and House (1963) studied the effect of the obstruent consonants (i.e., nasals, liquids, and glides were excluded) of American English on vowels in nonsense words of the form /hə 'CVC/ spoken in isolation, where the first consonant was always the same as the second consonant. Vowels were also spoken in words of the form /hVd/ and in isolation (/#V#/), contexts which the researchers presumed to have no effect on the vowel and thus permit an "ideal" vowel to be produced. The vowels in the /hVd/ and /#V#/ contexts were compared to the vowels in /hə 'CVC/ context. Stevens and House found that the extent of the effect of consonantal context on a vowel's midpoint formant frequency depends on the vowel, and that there are systematic differences in the effect depending on the place, manner, and voicing of the adjacent consonants. Using the same corpus, Stevens, House, and Paul (1966) studied the formant trajectories of the vowels, focusing on the second formant trajectory. They fit parabolas to the trajectories and chose as parameters the curvatures of the best-fitting parabolas, initial F2, midpoint F2, and final F2. The curvature was found to be affected by whether the vowel was tense or lax. No simple relationship was found among the effects of consonant context on the initial, midpoint, and final F2. Lehiste (1962) conducted an analysis of vowels in the context of the liquids and glides of American English, /l/, /r/, /w/, and /y/, in monosyllabic words uttered in a carrier phrase. Again, systematic influences of the consonant context on the vowel were described.

Lexical stress, defined in the present study as the stress placed on a syllable in the dictionary pronunciation of the word, is another factor found to influence vowel formant frequencies. Delattre (1969) performed a study of vowel reduction due to lexical stress. Vowels were studied in pairs of words or phrases in which a vowel appeared in the same context but was stressed in one case and unstressed in the other. An example of such a pair in English is "adapting/adaptation," where the /æ/ in the second syllable is examined. Delattre found that the formant frequencies for unstressed vowels tended to be closer to the "neutral" position (the center of the vowel quadrilateral on an F1-F2 plot) than for corresponding stressed vowels.

There are a few previous studies of formant trajectories in connected, meaningful speech. Stålhammar et al. (1973) measured midpoint formant frequencies of Swedish vowels from several speech styles: isolated vowels, nonsense words of the form /hVl/ without a carrier phrase, and connected read speech. The vowels in connected speech were analyzed separately as stressed long vowels, stressed short vowels, and unstressed short vowels in word suffixes. (There is a phonemic distinction between long and short Swedish vowels, which is similar to the tense/lax distinction in English, according to Fant, 1973.) Swaffield et al. (1961) and Koopmans-van Beinum (1980) did similar studies in British English and Dutch, respectively. All three studies found that formant frequencies for vowels in continuous speech tended to be closer to the center of the vowel quadrilateral on the F1-F2 plane than vowels in isolated words, though detailed differences between the formant frequencies of vowels in isolated words and continuous speech were not explained. Stålhammar et al. note that the shifts in formant frequency midpoint with increasing naturalness of speech style for long vowels are smaller than those for short vowels. The unstressed short vowels in word suffixes in connected read speech tended to be the closest to the center of the vowel quadrilateral of all the vowels.

Factors which have a weaker influence on vowel formants than those discussed above have also been investigated. These factors were not controlled in the present study, but they are considered in the interpretation of the results when necessary.

Vowels are influenced not only by the phonemes immediately adjacent but also by phonemes further away. In particular, vowels have been found to be influenced by the vowels on the far side of the surrounding consonants (transconsonantal vowel-vowel coarticulation). Öhman (1966), Magen (1984, 1989), and Manuel and Krakow (1984) studied vowel-vowel coarticulation in /VCV/ utterances. All researchers found that vowels are influenced by transconsonantal vowels. Öhman and Magen note that, in English, a transconsonantal vowel affects the region of the vowel formant trajectory near the boundaries of the vowel and the consonant. The region further away from the boundary, where the researchers assume the vowel makes its closest approach to the vowel target, is affected, but not as strongly.

Lieberman (1963) and Hunnicutt (1985, 1987) have investigated the effect of a higher-level factor, sentence redundancy (how well readers could guess a missing word from the context of the sentence), on the intelligibility of words. Although these researchers did not examine vowels specifically, they made some acoustic measurements on the words. Lieberman measured duration and amplitude, while Hunnicutt measured duration, amplitude, and some characteristics of the fundamental frequency (F0) contour. Hunnicutt's study was the larger of the two. She found that intelligibility and redundancy were well correlated in text-type sentences but not in spoken-type sentences and well-known adages. The acoustic measures, in turn, were not well correlated with intelligibility, though differences in the measures usually occurred in the expected direction when comparing the same word in high- and low-redundancy context.

Koopmans-van Beinum (1989) investigated another higher-level factor, the role of "given" vs. "new" information in a read text or conversational speech. The hypothesis is that content words which appear for the first time ("new information") in a long spoken sequence are pronounced more carefully than content words which had appeared previously ("given information"). Koopmans found that the vowels in new words are more distant from the center of the vowel quadrilateral in F1-F2 space than vowels in given words. However, she stresses that this was a pilot study on one speaker only.

Lindblom (1963) asserted that a vowel's duration determines whether its formants reach their target frequencies. In his data, shorter-duration vowels tended to have formant frequencies closer to the loci of adjacent consonants. (In Lindblom's thesis summary (1968), however, he expresses the view that factors other than duration affect vowel formant frequency.) The demonstration of the effects of other factors on vowels makes it unlikely that vowel variation can be explained on the basis of duration alone. This and the difficulty of varying duration independently of other factors led to the decision not to address the duration question directly in the present study.

Lindblom's study also raises the question of whether shifts in vowel formant frequencies are due to a natural tendency for vowels to "degenerate" into schwas (centralization), or whether vowels tend to assimilate to their consonant context. Lindblom's data seem to show that when vowels are produced "hurriedly," their formant frequencies are closer to the loci of the adjacent consonants. Stevens and House's data (1966) seem to show centralization when vowels are produced in context when compared to vowels produced in isolation, where they might be assumed to be more carefully articulated. Which, if either, of these explanations better describes the mechanism of vowel production? Nord (1986) considered this question. From his study of two-syllable words, Nord concluded that an unstressed vowel in the initial syllable assimilates to its consonantal context, i.e., its midpoint F1 and F2 frequencies are close to the presumed loci of its surrounding consonants. In contrast, an unstressed vowel in the final syllable of the word is centralized, i.e., its F1-F2 position tends to be close to the center of the vowel quadrilateral. Nord considered the centralization to be an instance of contextual assimilation where the vowel assimilates to the neutral position which the vocal tract assumes after saying the word in isolation. It may be true that, in general, vowels in prepausal syllables have a greater tendency to centralize than vowels in non-prepausal syllables. Why the two different kinds of contextual assimilation should occur in these different situations remains to be explained. The present study does not directly address the question of contextual assimilation vs. centralization, but the two possibilities will be considered in the interpretation of the results.

This survey of previous work indicates that further research examining continuous speech, especially spontaneous speech, is needed. Interactions among the factors found to influence vowels have not been thoroughly studied. For example, Delattre studied stress but did not vary the consonant context of the vowels, while Stevens et al. and Lehiste studied consonant context but did not vary stress. In particular, the effect of consonant context on vowels in connected speech should be studied. Stålhammar et al., Swaffield, and Koopmans-van Beinum did not control the consonant context in their studies. The majority of previous work has considered the midpoint formant frequency only. Future studies should consider the entire trajectory of the vowel formant frequencies, as was done by Stevens et al., Öhman, and Magen. The importance of formant trajectories will be discussed in the next subsection.

1.2.2 Previous Perceptual Experiments; Trajectory Shape Influences Vowel Perception

Experiments with Synthesized Vowels

Studies by Huang (1985, 1987), Di Benedetto (1987) and Lindblom and Studdert-Kennedy (1967) have considered the question: How does a person use time-varying formant frequencies to determine the identity of a vowel? Each study consisted of series of tests in which subjects were presented with synthesized vowels in nonsense words and asked to identify the synthesized vowel by making a forced choice between two vowels or two classes of vowels. Unless otherwise specified, all subjects were native speakers of American English.

Huang's study (1985) investigated the perception of stimuli with piecewise-linear formant trajectories in the mid- to high-vowel region. The steady-state portion of F1 was varied such that the stimuli were identified as /ɪ/ or /ɛ/ in one experiment and /ʊ/ or /ʌ/ in another experiment. Results were consistent with a theory of perceptual averaging of F1. The F1 frequencies at the steady-state portion of stimuli identified as the same vowel phoneme but having different trajectory shapes differed by up to about 20 Hz. Unfortunately, in this study, F2 was also varied, but only by half the change in F1 frequency on the Bark frequency scale (Zwicker, 1961). It may be argued that the change in F1 was perceptually more important.

Di Benedetto (1987) investigated the effect of the location (early or late) of the steady-state portion of piecewise linear stimuli on their perception. The vowels were along a continuum between /ɛ/ and /ɪ/. The results obtained can be accounted for by hypothesizing a weighted average of F1 in which the early portion of the vowel is given more importance than the later portion.

Lindblom and Studdert-Kennedy's study (1967) suggests that, unlike F1, which seems to be perceived with averaging, F2 is perceived with an overshoot. The vowel formants in their study had parabolic trajectories. The F1 trajectory was the same for all stimuli, while the F2 and F3 trajectories were either concave upward or downward. The midpoint values for F2 and F3 were varied such that the vowels were on a continuum between /ʊ/ and /ɪ/. The midpoint F2 frequencies of perceptually equivalent stimuli with different trajectory shapes differed by up to 250 Hz.

Lindblom and Studdert-Kennedy's study (1967) investigated F2 in the high-vowel region. Using a similar experimental design, Huang (1987) examined F2 in the low vowel region. The midpoint F2 frequency for the vowel was varied over a range of values appropriate for the vowel continuum /æ,ɑ/. The vowel trajectories in the nonsense words were parabolic. Results were mixed, but there was some evidence supporting the hypothesis of perceptual overshoot for F2.

Although the experiments described above only provide evidence about formant trajectory perception for a limited set of trajectory shapes and for a limited set of vowels, some conclusions relevant to the present acoustic study can be drawn. First, it is clear that vowels with the same formant frequencies at the durational midpoint but different trajectories are sometimes perceived as phonemically different vowels. Therefore, it is important that formant trajectories be investigated in the acoustic study as well as formant frequencies at the midpoint of a vowel. Second, F1 and F2 seem to be perceived differently in the vowels studied. In the acoustic study, it may be asked if F1 and F2 have different acoustic characteristics also. Finally, the results of the perceptual experiments provide an indication of the magnitude of the perceptual effects of formant trajectories when no lexical information is present.

Experiments with Natural Vowels; Perceptual Studies and Related Acoustic Studies

Natural vowels, i.e., vowels elicited from a speaker, have been found to be identified quite well under the best conditions, even when presented with no lexical or semantic information. For example, Assmann et al. (1982) report 4.09% error for the identification of ten vowels produced and presented in isolation, with vowels from each speaker presented separately (their Table AII). In contrast, for the identification of twelve unstressed Dutch vowels excised from free conversation (with speakers presented separately), Koopmans-van Beinum (1980) found an error rate of 67.0% (from her Table 7.2, averaged over all speakers). Many factors which affect the difficulty of identifying vowels have been investigated. The effect of several factors will be qualitatively described in the following.

Several researchers have demonstrated the importance of formant trajectories in the identification of natural monophthongal vowels. Tiffany (1953) and Assmann et al. (1982) showed that constant-duration vowel portions gated out from isolated vowels are more poorly identified than the original vowels, which had speaker-controlled onsets, offsets, and durations. Jenkins et al. (1983) excised portions of vowels from the centers of CVC nonsense words. They found that both the excised portions, whose duration was 50% to 65% of that of the original vowel, and the "centerless" CVC syllables (with the temporal relationships preserved) allowed identification of the vowel at accuracies comparable to those for the original syllable. However, if the excised portions were trimmed to a constant duration, which reduced the information about the formant trajectory and neutralized any duration cues, identification was significantly worse.

Noting the importance of formant trajectories, researchers have attempted to capture their essential characteristics with various parameterizations. Assmann et al. (1982) and Nearey and Assmann (1986) tried to relate measures of formant trajectory movement to the identification of vowels. Assmann et al. used formant slopes and duration ("dynamic information"), as well as center formant frequencies and F0 ("static information") to classify isolated vowel tokens using statistical classification techniques. They found that vowels were more often correctly classified (i.e., assigned to the phoneme class intended by the speaker) using the dynamic information and the steady-state information than using the steady-state information alone. Nearey and Assmann used three different parameterizations of the formant trajectory and a statistical classification procedure to predict the identification error rates of vowel stimuli used in their perceptual experiment. The three different parameterizations were (1) initial and final F1 and F2, (2) initial F1 and F2 and the average slopes of F1 and F2 through the whole vowel, and (3) initial F1 and F2 and the direction of formant movement in the F1-F2 plane. The first method, initial and final F1 and F2, most closely predicted the actual identification results, but the other parameterizations allowed similar predictions, so the authors do not rule out any method until further experiments can be done.

Besides the importance of formant trajectories, some other points can be noted from the previous studies. Particularly relevant to the present study are observations of the effects of context and style of speech on vowel identification, since these factors are investigated further. Strange et al. (1976) found that vowels produced and presented in CVC nonsense words can be identified with fewer errors than vowels produced and presented in isolation (though some of the errors in Strange et al.'s experiment may be due to orthographic interference, Assmann et al., 1982, see below). Kuwahara and Sakai (1972) showed for Japanese that the center vowel in CVCVCV syllable sequences could be better identified if presented in the complete three-syllable sequence than if the preceding or following syllable, or both, were omitted. This perceptual result may correspond to the transconsonantal vowel-vowel coarticulation noted in acoustic studies described previously. Verbrugge et al. (1976) studied the perception of vowels produced in nonsense words in what he termed "destressed" positions in rapidly spoken sentences. They found that these destressed vowels, when presented in the nonsense word without the sentence, were more difficult to identify than vowels produced in the same nonsense word in citation form. The error rate for destressed vowels dropped when the vowels were presented in their full sentence context. Unfortunately, stressed vowels produced in a sentence were never used in this experiment, so a comparison between stressed and destressed vowels in sentence context cannot be made. Koopmans-van Beinum (1980) compared the identification of Dutch vowels in different styles of speech. Vowels excised from conversational speech were found to be much more difficult to identify than vowels produced in isolation.

Finally, some methodological guidelines for identification experiments with natural speech can be noted from the previous studies. Assmann et al. (1982) show that "orthographic interference" can artificially raise error rates in vowel identification. Specifically, error rates were much lower in an isolated vowel identification task when the listeners answered by repeating the vowel orally than when the listeners answered by marking the corresponding hVd word on an answer sheet (e.g. "had" for /æ/, "hud" for /ʌ/). Other studies indicate that listeners identify vowels more accurately if given contextual information relating to speaking rate and speaker characteristics. Strange et al. (1976), Verbrugge et al. (1976), and Assmann et al. presented their identification tests either by mixing vowels from all speakers in random order or by presenting vowels from one speaker at a time. All studies showed that error rates were lower in the one-speaker condition. Verbrugge et al. recorded nonsense words in destressed positions in rapidly spoken sentences. The vowels in the nonsense words were more accurately identified when presented in the sentence than when presented in the nonsense word alone. Since the vowels were always presented in the mixed-speaker condition, it could be argued that speaker-normalization accounted for the improvement. When the nonsense words were presented together with citation-form isolated vowels from the same speaker, however, error rates increased. The researchers concluded that the sentence contained information about the speaking rate, which allowed listeners to normalize the vowel's duration. Koopmans-van Beinum also notes that a large proportion of identification errors made on Dutch unstressed vowels excised from conversational speech were long vowels mislabelled as short vowels. (There is a phonemic long/short distinction in Dutch.) Incorporating speaking-rate information into the vowel stimulus presentation, if possible, seems desirable.

As with the acoustic studies, the majority of perceptual studies with natural speech have been done with vowels produced in isolation, in isolated words, or in monosyllabic nonsense words in carrier phrases. In the present study, the methods used are similar to those in previous studies, but the focus will be on examining the identification of vowels excised from connected speech. The relationship of the identification results to the acoustic characteristics of the vowels will be investigated.

1.3 Approach to Questions

The present study addresses questions of vowel variability and its effects on vowel perception. To approach answers to these questions, an acoustic analysis of connected, meaningful speech was conducted. For the purposes of the proposed study, laboratory-recorded read sentences which are not semantically anomalous are examples of connected, meaningful speech. Spontaneous speech was also be examined. These styles of speech are the focus of the present study, because they are more similar to natural speech than isolated words or words in carrier phrases. In addition, perceptual tests were run using as stimuli the speech tokens which were examined in the acoustic analysis. Listeners were asked to identify the vowels given varying amounts of information about the vowels' contexts.

Those conditions which have been found in previous work to result in overlapping vowel regions on a midpoint F1-F2 plot were chosen for more careful study. For example, previous results suggest that F1-F2 midpoint regions for lax vowels in the context of liquids and glides overlap greatly. These conditions are most interesting because it may not be possible to classify the resulting vowels using a simple measure such as their formant frequencies at the midpoint. Also, they are presumably particularly confusable by listeners.

A specialized database focusing on the cases of vowel region overlap was designed and recorded from four speakers (two men and two women). To keep the scope of the study manageable, the vowel set was limited to /**i**/, /ɪ/, /ɛ/, /**e**/, and /ʌ/. This vowel set includes minimum pairs which illustrate the vowel feature distinctions high/non-high (/**i**/-/**e**/ and /ɪ/-/ɛ/), front/back (/ɛ/-/ʌ/), and tense/lax (/**i**/-/**e**/ and /**e**/-/ɛ/). Although /**i**/ and /**e**/ are usually diphthongized in American English, they are single-target vowels (Lehiste and Peterson, 1961) and were treated as monophthongs.[1]

The effects of three factors previously found to affect the midpoint formant frequencies – consonantal context, lexical stress, speech style – were investigated in connected speech.

[1]The author offers the following intuitive argument to distinguish between a true diphthong, such as /ɑʸ/, and a diphthongized single-target vowel, such as /**e**/. A vowel which can be identified as /**e**/, though it may not sound natural, can be synthesized with steady-state formants, while /ɑʸ/ cannot be.

Differences from the results found in isolated vowels and words will be described.

The vowels' acoustic properties were represented in terms of formant frequencies, the natural resonances of the vocal tract during vowel phonation. Formant frequencies have been shown to be the main determinants of vowel quality, at least in the case where formants are well-separated (see, for example, Carlson et al., 1979). Also, in the context of distinctive feature theory as defined by Jakobson et al. (1969), the acoustic correlates of distinctive features for vowels are often described in terms of formant frequencies. It may be argued that formant frequencies are too difficult to measure reliably in the acoustic signal, and that a more robust representation of the vowels in terms of energy prominences should be used. However, the time-varying frequency location of the spectral prominences is easily expressed in terms of formant tracks. If the formant tracks are hand-corrected, large errors are unlikely. The spectral shape at any point in time can be calculated from the formant tracks, as long as bandwidths of the prominences are not very different from typical values (Fant, 1970). These arguments led to the decision to assume that, for the purposes of the present study, the formant frequency trajectories are an adequate parameterization of the vowel spectrum and the vowel's time-varying behavior.

Part of the study was concerned with finding the aspects of the formant trajectory shape which are important for the identification of vowels. Previous studies have concentrated on the formant frequencies at one point in time. Less attention has been given to the formant trajectory, which for the present study is considered to include the midpoint values, the duration, and the shape of the formant path in time.

The vowels are treated as multi-dimensional entities. The characterization of vowels in terms of distinctive features is one useful multi-dimensional description. Vowel phonemes have varying degrees of height, backness, tenseness, retroflexion, and roundness. (However, retroflexion and roundness will not be considered in this study.) Vowel height has been shown to correspond to F1 (or possibly a combination of F0 and F1), backness to F2 (or possibly a combination of F2, F3, and F4), and tenseness to duration and trajectory shape. Many studies have been done investigating the acoustic correlates of vowel height, backness, and tenseness. See, for example, Fant, 1970, for the acoustic theory; Miller, 1953, and Traunmüller, 1981, for work on F1; Fant and Risberg, 1963, and Delattre et al., 1955, for work on F2; and Lehiste and Peterson, 1961, for work on formant trajectories and the tense-lax distinction.

The effect of a factor on each vowel dimension will be described. For example, a preceding /**l**/ may cause the vowel /**ɛ**/ to be more back than a preceding /**d**/ does, though the effect of these consonants on vowel height is the same. Decomposing a factor's effect into its effect on each vowel dimension shows which aspects of the vowel change with varying contexts and which aspects remain unchanged.

To address the question of how a listener recognizes a vowel, the following approach was taken. It was determined how well listeners can identify the vowel tokens when presented alone or with their immediate consonant contexts. A simple perceptual model attempted to simulate listeners' responses given the acoustic data for the vowel tokens. The following stages were tested with the perceptual model. First, the vowels were identified as well as possible given only the midpoint formant frequencies. From the design of the database, this simple measure should not be enough to identify all the vowels, because many vowels with different phonemic labels have similar midpoint values. As the next step, the shape of the vowel formant trajectory was used to resolve confusions. When confusions still occurred, attempts to resolve them were made by explicitly taking consonant context into account.

The ultimate goal of a speaker when producing vowels is to communicate meaningful words and sentences, and the ultimate goal of a listener is to understand meaningful words and sentences. Lexical access, i.e., how a listener recognizes a word, will therefore be a consideration in the interpretation of the results of the study. For example, the identification tests may show that even considering midpoint formant frequencies, formant trajectory shape, and consonant context together, it is not possible to identify vowels perfectly. It would then be asked if there are certain vowel features which listeners identify correctly even if the vowel identification was wrong (i.e. even if other features are not identified correctly). If the listeners can still understand the sentence in which the vowels appear, it can be concluded that human listeners can understand a spoken message without absolutely identifying all vowels, although it may be necessary to correctly identify some vowel features. Implications for theories of lexical representation of speech could be explored. For example, if the identification of some but not all distinctive features is needed for identifying a word, it could be hypothesized that only those distinctive features are specified for that word in the mental lexicon, or at least that some features are weighted less heavily in making a match.

Two methodological considerations are crucial to the interpretation of the results. First, transcription of the vowels to be studied must be considered. For the purposes of the proposed study, vowels should be labelled as the vowel that was "intended." The meaning of "intended" must be defined in a consistent way. Second, segmentation of the signal was a necessity for the present study, although it is clearly impossible to isolate segments of speech from influences of adjacent segments. It was necessary to choose portions of the signal to analyze or to present to listeners. The use of segmentation does not imply adherence to a theory of perception which requires segmentation by the same conventions.

Two other fundamental issues are not explicitly dealt with in the present study. Variation in the data due to speaker characteristics was eliminated by analyzing a large amount of data from a small number of speakers, each speaker being analyzed separately. Trends for the different speakers were compared in the interpretation of the data. Language-specific differences were also ignored until the interpretation of the data, since only American English was analyzed.

Chapter 2

Experimental Method

2.1 Acoustic Study

2.1.1 Design of the Corpus

The corpus for the study was specially designed to be well-controlled with respect to the vowels of interest, their immediate consonant context, and their degree of lexical stress. The corpus consists of three kinds of read text: a story several paragraphs long, real words in a carrier phrase, and nonsense words in a carrier phrase. These three read speech styles will be referred to in short as "read," "carrier phrase," and "nonsense," respectively. In addition, the speakers were asked to retell the story after they had read it. Words which appeared both in the read story and the retold story were collected to form the spontaneous speech corpus.

The consonant-vowel-consonant (CVC) sequences chosen for the study are shown schematically in Figure 2.1. The vowels to be studied are /i/, /ɪ/, /ɛ/, /e/, and /ʌ/. The consonant contexts to be studied are /b/, /d/, /g/, /w/, /r/, /l/. The vowels were chosen to include minimum pairs in the features height, frontness, and tenseness. The /w/, /r/, and /l/ contexts were chosen because they were found in a preliminary study to affect the vowel formant frequencies the most of the consonants. They are the consonants for which the tongue body is constrained in American English to be [+back]. The stop contexts were chosen as a contrast to the liquid and glide contexts, since the tongue body is less constrained in the articulation of the stops. As seen in Figure 2.1, the consonant context consists of one of the consonants mentioned above on one side of the vowel and an alveolar consonant on the opposite side. The alveolar context, which occurs frequently in English, was chosen to maximize the number of real English words which could represent the contexts. The manner of articulation of the alveolar consonant varies, with the restriction that nasals are not allowed, since nasals tend to obscure the F1 prominence of adjacent vowels. This variation was allowed in order to find enough real words containing the desired CVC sequences.

For purposes of analysis, the vowel tokens must be categorized according to criteria independent of their acoustic and perceptual properties. Therefore, the vowels were categorized according to their dictionary pronunciation (*Webster's Ninth New Collegiate Dictionary*, 1985), which is the citation-form pronunciation agreed upon by a large number of speakers of General American English. For example, the vowel in the first syllable of the word "question" is put in the same category as the vowel in the word "head," which is labelled /ɛ/. It is assumed that the dictionary pronunciation is the speaker's "intended" pronunciation.

The vowels studied carry primary or secondary lexical stress. The intention was to exclude schwas from the database, and it can be argued for almost all the vowels in the contexts to be studied that they are not reducible to a schwa. For example, in the word "disobedience," the first vowel, (/ɪ/), carries secondary stress by the principle of alternating stress in English.[1] That is, the first syllable is two syllables away from the primary-stressed syllable, so it must be stressed, and the vowel between those two syllables can be reduced. In other cases, the secondary-stressed syllable is in the less-stressed word in a compound word (e.g. /i/ in "bittersweet"). A few cases where the vowel might be reducible were unavoidable. Stress shift is another phenomenon which may cause discrepancies between the nominal level of lexical stress and the realized level of stress (as judged by acoustic measurements or human perception). By stress shift is meant the change in stress pattern of a word when it is placed in a phrasal context.[2]

[1]Morris Halle, personal communication.

[2]An example is the stress pattern in the word "thirteen," which carries its main prominence on the second syllable in isolation but on the first syllable (or equal prominence on both syllables) in the phrase "thirteen men." No assumptions about the linguistic origins of this phenomenon will be made in the present study, but see Liberman (1977) for a discussion.

	C	V	C
a.	b	i^y	any alveolar (except nasal)
	d	ɪ	
	g	e^y	
	w	ɛ	
	r	ʌ	
	l		
b.	any alveolar (except nasal)	i^y	g
		ɪ	l
		e^y	
		ɛ	
		ʌ	
c.	any alveolar (except nasal)	i^y	w
		e^y	

Figure 2.1: Schematic diagram of CVC sequences chosen for the present study. Three types of CVC sequences occurred in the database, shown by a., b., and c. An initial consonant is chosen from the first C column, a vowel from the V column, and a final consonant from the second C column.

Table 2.1: Key describing categories of words in cells of Tables 2.2 and 2.3.

primary stress, C-V-alv	secondary stress, C-V-alv
primary stress, alv-V-C	secondary stress, alv-V-C

Again, the dictionary pronunciation, a criterion independent of acoustics and perception of individual tokens, is used to categorize the vowel by stress level.[3]

For each CVC sequence, two words were sought, one for each level of lexical stress. Five repetitions of these words were then embedded in a story to be read by the speakers. In an attempt to lessen the effects of factors other than consonant context and lexical stress on the vowel of interest, restrictions were applied to the words. To lessen the duration variation of the vowels, only polysyllabic words were used. (Port, 1981, showed that vowel durations in a word tend to vary inversely with the number of syllables in the word, but that the duration difference was greatest between mono- and bisyllabic words.) Also, in the read text, a syllable containing a vowel to be studied was never placed in a prepausal position. It was not always possible to find a suitable word, and therefore, coverage of the contexts was not quite complete. In some cases, a word containing a voiceless stop instead of the voiced stop consonant of the same place of articulation was accepted. A palatal consonant was accepted in place of the alveolar in some alternative words. The words chosen for each CVC are shown in Tables 2.2 and 2.3. A key to the tables of words appears in Table 2.1.

Other factors which may affect the vowels were not controlled in the read story. Segmental factors include the manner and voicing of the alveolar consonant of the CVC and transconsonantal context of the vowel. An example of a prosodic factor is phrasal stress, in particular, the presence or absence of pitch accent in the word, as defined by Pierrehumbert (1980). Whether syllable boundaries occur in or adjacent to the CVC is

[3]A vowel token which was "reduced," as judged by acoustic measurements or human perception, was not omitted from the database unless it was impossible to measure formants. This only occurred in one case: /ʌ/ in speaker RU's first read occurrence of the word "crustacean." Another token of the word was substituted.

Table 2.2: Words representing stop contexts. Vowels and contexts to be studied are underlined. *** means that the category was represented by a nonsense word only. Categories represented by real words were also represented by nonsense words. — means that the category is not represented. Words in parentheses are alternative words representing the CVC. Key to cells in Table 2.1.

	/b/		/d/		/g/	
/i/	disobedience	lobbied	indecently	candied	geezers	fogeys
	—	—	—	—	fatigue	***
/ɪ/	abysmal (bittersweet)	tidbit	discipline (condition)	disobedience (criticism)	schizoid	schizophrenic
	—	—	tidbit	—	signatures	***
/e/	verbatim	exacerbated	lackadaisical (statehouse) (crustacean)	accommodated	gator	alligator
	—	—	—	—	***	***
/ɛ/	alphabetical	alphabet	detriment	detrimental	spaghetti	***
	—	—	—	—	integrity (protection)	architecture
/ʌ/	rebuttal	filibuster	industrial	industrialization	guttural	customarily
	—	—	—	—	***	***

Table 2.3: Words representing liquid-glide contexts. Vowels and contexts to be studied are underlined. *** means that the category was represented by a nonsense word only. Categories represented by real words were also represented by nonsense words. — means that the category is not represented. Words in parentheses are alternative words representing the CVC. Key to cells in Table 2.1.

	/w/		/r/		/l/	
/i/	queasiness	bittersweet (seaweed)	unreasonable	decrease (noun)	obsolete	isosceles
	seaweed	***	—	—	conceal	***
/ɪ/	inquisitive	ventriloquism	criticism	aristocratic	literature	litigation
	—	—	—	—	diligently	***
/e/	dissuaded	antiquated	radio (celebration)	adulterated (frustrating)	complacent (population)	legislator (accumulated)
	jaywalking	***	—	—	azalea	***
/ɛ/	question	questionnaire	incredibly	preservation	athletic (legislator)	***
	—	—	—	—	delta	celebration
/ʌ/	Fuzzy Wuzzy	***	frustrating	crustacean	illustrious	***
	—	—	—	—	***	insult

another factor.[4] Syntactic factors include word class (whether the word is a noun, verb, adjective, etc.) and morpheme class (whether the vowel occurs in an affix, word root, or compound word). Semantic factors include the effect of given versus new information and the predictability of the word. Finally, the production of a vowel in a word may be affected if there are other words in the lexicon which differ only in the vowel.

While it is hoped that the factors mentioned above have a much smaller effect on the vowels than consonant context and lexical stress, the corpus provides two checks. First, several CVCs can be studied in more than one word in the read story. If an effect is limited to a particular word, the limitation is likely to be detected in these cases. The effect may then be suspected to arise from the segmental, prosodic, syntactic, or semantic factors mentioned above. Second, all the CVCs appear in nonsense words read in a constant carrier phrase. In the nonsense word corpus, all factors are controlled, including the factors mentioned above which could not be controlled in the read story.

The carrier phrase, which was used both for the nonsense word corpus and as the frame sentence for some repetitions of the chosen words, was designed so that the words to be studied would not carry an onset rise or a pitch accent. An onset rise occurs at the beginning of a prosodic phrase (Maeda, 1976). A pitch accent denotes the main stress in the prosodic phrase, which could change location depending on whether there is contrastive or emphatic stress. The carrier phrase is "Say a magenta ____ once" with the underline on "once" indicating emphasis. "Magenta" should carry the onset rise, and "once" should carry the pitch accent. The nonsense words used were similar to the words "dedication" and "dedicated," with the CVC substituting for the "ded-" in the first syllable. Therefore, in the nonsense words, all the CVCs appear once with primary stress, once with secondary stress, and always in a four-syllable word with schwas as the vowels' transconsonantal context.

For reference, the vowels were also recorded in the /hVd/ context for each speaker. The /hVd/ nonsense word was spoken in a carrier phrase.

A total of 854 tokens were analyzed for one male speaker (JS). Approximately 200 tokens were analyzed for each of the remaining three speakers. A summary of information about

[4]There were only two clear cases of a syllable boundary occurring within the CVC: in the words "jaywalking" and "seaweed."

Table 2.4: Corpus information.

Speaker	Style	No. reps. per word	No. vowel tokens
EE	Nonsense	0	0
	Real word in carrier phrase	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Read story	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Spontaneous (retold story)	1	11 /i/, 14 /ɪ/, 18 /e/, 14 /ɛ/, 9 /ʌ/
JS	Nonsense	2	36 /i/, 32 /ɪ/, 36 /e/, 32 /ɛ/, 32 /ʌ/
	Real word in carrier phrase	2	34 /i/, 36 /ɪ/, 44 /e/, 32 /ɛ/, 24 /ʌ/
	Read story	5	85 /i/, 88 /ɪ/, 110 /e/, 76 /ɛ/, 60 /ʌ/
	Spontaneous (retold story)	Variable, up to 5	15 /i/, 11 /ɪ/, 30 /e/, 22 /ɛ/, 19 /ʌ/
MP	Nonsense	0	0
	Real word in carrier phrase	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Read story	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Spontaneous (retold story)	1	5 /i/, 10 /ɪ/, 15 /e/, 9 /ɛ/, 8 /ʌ/
RU	Nonsense	0	0
	Real word in carrier phrase	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Read story	1	17 /i/, 18 /ɪ/, 22 /e/, 16 /ɛ/, 12 /ʌ/
	Spontaneous (retold story)	1	11 /i/, 12 /ɪ/, 17 /e/, 13 /ɛ/, 10 /ʌ/

the corpus appears in Table 2.4. Speaking rate was not controlled, but a limited measure was made after collection of the data. The phoneme rates of the words from which the vowel tokens were taken are shown in Table 2.5. A listing of the nonsense sentences, the read story, and a representative part of a retold story can be found in Appendix A.

Table 2.5: Average phoneme rates in phonemes per second for speakers JS, RU, EE, and MP. Rates were measured for the words (sometimes including one adjacent syllable from a neighboring word) from which the vowel tokens were taken. The words were categorized according to speech style. Pauses were omitted.

	JS	RU	EE	MP
nonsense	11.0	–	–	–
carrier phrase	12.6	17.9	14.5	15.9
read story	12.5	16.2	14.5	16.6
spontaneous	15.2	13.6	14.2	13.1

Table 2.6: Speaker information. Age is age at time of recording.

Initials	Male/Female	Age	Education	Childhood Residence
EE	Female	24 yrs.	PhD candidate	Kansas City, MO
JS	Male	21 yrs.	Undergraduate	Cambridge, MA
MP	Male	26 yrs.	PhD candidate	Norwell, MA
RU	Female	31 yrs.	PhD	Chicago, IL

2.1.2 Speakers

Four speakers, two males and two females, who do not have markedly breathy, nasalized, or high-pitched speech were chosen. That is, speakers were chosen whose formants were likely to be clearly visible on a spectrogram. They are all young, native speakers of General American English. Except for JS, all are researchers in a field related to speech science. However, none of the speakers knew of the objectives of the experiments at the time of recording. A summary of information about the speakers appears in Table 2.6.

2.1.3 Recording Procedure and Equipment

Recording of the speakers was done in a sound-treated room using an Altec 684B microphone whose frequency response was flat within 2 dB between 70 Hz and 2000 Hz and within 5 dB between 2000 Hz and 5000 Hz (according to an in-house calibration), a Nakamichi LX-5 cassette deck, and a Shure microphone mixer. The speech was recorded on TDK AD60 cassettes (Type I, normal bias, EQ 120 sec) without Dolby.

Speakers were first instructed to read the story as if reading a newspaper story to a friend of the same age. If they made an error, they were asked to repeat the sentence immediately. They were interrupted periodically to retell the story, during which time they could refer to the written story to aid their memories. The story was read and retold twice in order to provide back-up stimuli in case of uncorrected errors and to collect enough spontaneous speech. Then, the nonsense sentences were read.

Speaker JS was recorded in one three hour session. The other speakers were recorded in two one and one-half hour sessions.

2.1.4 Transcription (Phonetic and Phonemic)

The recorded speech was digitized at 16 kHz using a Nakamichi LX-5 or BX-300 cassette deck and a Digital Sound Corporation A/D converter onto a Symbolics Lisp Machine. Variation of the speed between recording and playback cassette decks was within 2%. The words containing the vowels of interest were excised, segmented, and transcribed by hand while referring to the sound pressure waveform and a spectrogram. The spectrogram was computed with a 400 Hz bandwidth Hamming filter, a frame rate of 1000 per second and a dynamic range of 25 dB. Both phonemic and phonetic transcriptions were assigned, using the software tools *Spire*, *Caspar*, and *AAT* (Cyphers et al., 1986; Kassel, 1986). Phonemic transcriptions corresponded to the dictionary pronunciation. Phonetic transcriptions were assigned according to the realization of the phoneme. For example, the "t" in "exacerbated" was marked /**t**/ in the phonemic transcription and /ɾ/ in the phonetic transcription. Only the phonemic transcription for the vowels was used in the analysis.

Segmentation was straightforward except in the case of liquid/glide vowel boundaries. In these cases, a boundary was set only if higher formants appeared on the spectrogram for the presumed vowel but not for the presumed consonant. Typically, such a boundary corresponded to a 10 dB rise in the amplitude of F3 and/or F4 within two pitch periods going from the liquid or glide to the vowel. The point of presumed maximum closure for the liquid or glide (the point of lowest F2 for /**w**/ and /l/ and lowest F3 for /ɾ/) was marked for all liquids and glides. Examples are shown in Figure 2.2. The point of maximum closure for a liquid or glide in a cluster (e.g., /**kw**/) was allowed to be in an aspirated region if formants were visible. In the case of unvoiced-stop vowel sequences, the vowel boundary was placed at the onset of voicing for the vowel.

2.1.5 Measurement of Formant Frequencies

Formants were tracked throughout the duration of each vowel by calculating LPC (Linear Prediction Coefficient) peaks at 5 ms intervals and correcting discontinuities by hand, referring to the spectrogram. For F1 and F2, the LPC peaks for a few points in time were checked against the wide-band spectrum calculated by centering a Hamming window at point of highest amplitude in the beginning of a pitch period (presumed to be the closed-

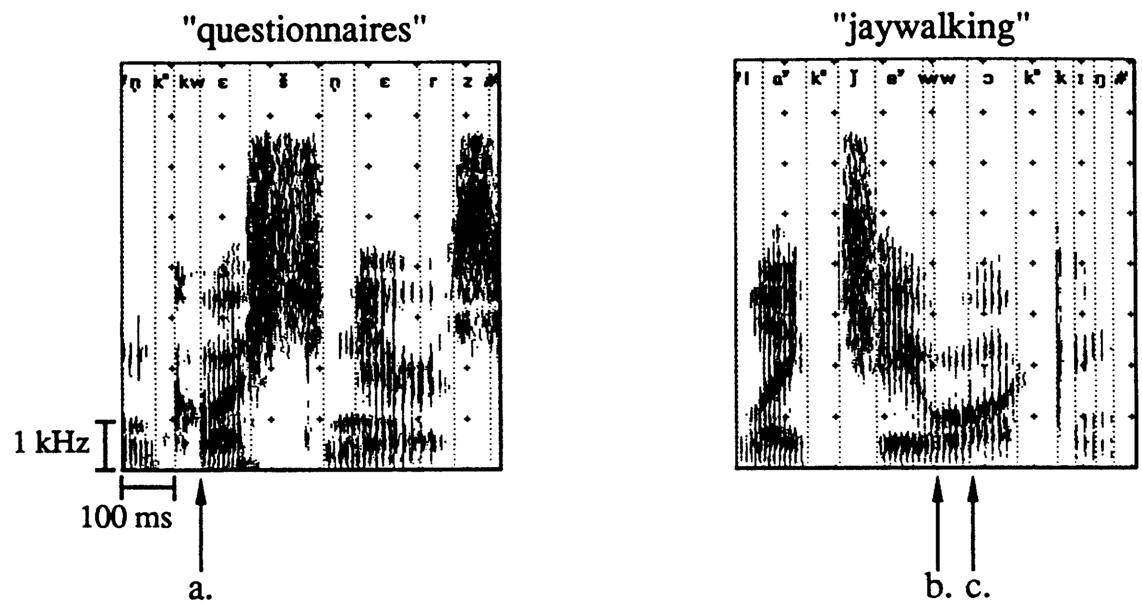

Figure 2.2: Examples of segmentation of /w/ in the words "questionnaires" and "jay-walking." If no sudden rise in amplitude of F3 or F4 in the glide-vowel transition can be seen, only the point of maximum closure of the vocal tract (for /w/, the point where F2 is lowest) is marked, as shown by **a.** If a rise in amplitude can be seen, a boundary between the glide and vowel is set, as shown by **c.** The point of maximum closure, **b.**, is also marked.

glottis portion). Where there was a discrepancy, the value of the wide-band spectral peak was chosen. F4 was sometimes difficult to distinguish from F5 and, therefore, measurements of F4 were less reliable than measurements of F1, F2, and F3.

The window lengths for the LPC and wide-band spectrum calculations were different for the male and female speakers, since they had different average fundamental frequencies. The average F0 for both female speakers was approximately 180 Hz, and the averages for the males were 140 Hz (MP) and 110 Hz (JS). The window lengths for the LPC were 15 ms and 25.6 ms for the females and males, respectively. The window lengths for the wide-band spectrum were 4 ms and 6 ms for the females and males, respectively. The spectrogram was calculated with the same parameters for all speakers.

To check the consistency of the formant-tracking method, formants were measured twice on thirty-six JS vowel tokens. The rms difference in measurements over the center 50% of the trajectory was calculated for each token. The maximum of this measure for the thirty-six vowels was 61 Hz, 71 Hz, 114 Hz, and 237 Hz for F1, F2, F3, and F4, respectively. The average over the thirty-six vowels was 21 Hz, 21, Hz, 36 Hz, and 66 Hz for F1, F2, F3, and F4, respectively.

2.2 Perceptual Tests

2.2.1 Stimulus Preparation

The vowels collected from the four speakers were presented to listeners for identification. The vowels were presented either alone (i.e., just the part of the signal between the vowel boundaries set by hand, as described in Section 2.1.4 on transcription), called the "no context condition," or with the two adjacent consonants (whose boundaries were hand-set), called the "CVC condition." In some cases, boundaries were not set for a liquid or glide, as explained above. In these cases, the point of maximum closure as determined during hand-transcription for the liquid or glide was taken as the boundary of the stimulus for both conditions. That is, when the point of maximum closure coincided with the vowel onset (or offset), the beginning (or end) of the stimulus was the same in the "no context" and CVC conditions, because the beginning (or end) of the vowel was also the beginning (or end) of the consonant. The point of maximum closure coincided with the vowel onset or offset in 10% of the vowel tokens of the entire database.

To smooth the abrupt changes in signal amplitude which arise when a vowel token was excised from an utterance, the onset and offset of the signal were tapered with a raised half-cosine window. The window was 5 ms long and extended 2.5 ms to each side of each boundary of the token.

2.2.2 Stimulus Presentation and Instructions

Two separate sets of tests were run: one set with only tokens from JS, called the single-speaker tests, and one set with tokens from all four speakers, called the four-speaker tests. In the four-speaker tests, each speaker was presented separately. Approximately 200 of JS's 850 available vowel tokens were presented as stimuli in the four-speaker tests, so the number of stimuli from each speaker was comparable.

Each stimulus was played three times in rapid succession. After this, the stimulus was not repeated. In the single-speaker tests, two responses were required of the subject. First, he or she circled one of the five vowels on an answer sheet: /**i**/, /**ɪ**/, /**e**/, /**ɛ**/, and /**ʌ**/, spelled "iy," "ih," "ey," "eh," and "uh" respectively. Then, he or she transcribed the stimulus using any of the American English phonemes. The second response showed how well the subjects could identify the consonant context in the "no context" and CVC conditions. Five seconds were provided for responding. In the four-speaker tests, only the first response was required, and 1.5 seconds were provided. For all tests, though subjects were required to identify each stimulus by making a forced choice among the five vowels, they were encouraged to also indicate which vowel they really heard from the full vowel set when it did not agree with the forced choice. This way, seemingly anomalous vowel confusions can be checked.

The perceptual tests were divided into one-hour sessions. In the single-speaker (JS) tests, the vowel was always presented in the "no context" condition for half of the session and in the CVC condition for the other half. The order of the conditions in a session alternated to balance any learning effects. In the four-speaker tests, each one-hour session consisted of eight segments of approximately 100 stimuli from each speaker in turn. The "no context" and CVC conditions alternated between segments.

Listeners attended up to two one-hour sessions consecutively. There were four sessions in all for the single-speaker tests and two sessions for the four-speaker tests.

As discussed in the introduction, previous studies have shown that long vowels excised from continuous speech and presented in identification tests tend to be mislabelled as short vowels (Koopmans-van Beinum, 1980; Verbrugge, et al., 1976). This kind of error may be avoided if the listener is able to normalize for the speaking-rate. In preliminary identification tests for the present study, a method of providing speaking-rate information was explored. The stimuli were spliced together with a processed version of the surrounding portion of the original word.[5] The processed signal, which was the smoothed LPC error, was meant to have the prosodic characteristics of the original word such as duration, pitch, and amplitude without the word being identifiable.[6] Preliminary tests were run with five phonetically sophisticated listeners and 170 vowel tokens. Some listeners felt subjectively that the processed context helped them, while others found it distracting. However, no statistically significant improvement from the presence of the processed context was found using McNemar's test (Gillick, 1989) in the performance of any of the listeners. The major problem seems to be that the processed context and the unprocessed vowel stimulus dissociate auditorily. Low-pass filtering was tried as an alternative type of processing, but the stimuli did not sound more natural than in the first attempt. Therefore, it was decided that, though it is desirable to provide prosodic information with the vowel stimuli, finding the right method is beyond the scope of this study. In the reported tests of this study, no attempt was made to provide prosodic information from the greater sentence context with the stimuli.

2.2.3 Listeners

The ten listeners are native speakers of American English with no noticeable regional accent and no history of hearing problems. Five listened to the single-speaker (JS) tests, and five others listened to the four-speaker tests. They range in age from twenty-four

[5]This is similar to an approach suggested by Dennis Klatt, personal communication.
[6]The idea and computer code for smoothed LPC error was provided by Nancy Daly.

to forty-six years. They all work in the field of speech science and are phonetically sophisticated listeners, but none knew of the objectives of the experiment at the time of the tests. Some listeners have knowledge of other languages, but they were instructed to listen to the stimuli as American English sounds.

2.2.4 Equipment

The perceptual tests were recorded on TDK AD60 cassettes (Type I, normal bias, EQ 120 sec) without Dolby. The tests were run in two locations. One was a quiet office with a Nakamichi BX-300 cassette deck and Sennheiser HD 222 headphones. The other location was a sound-treated room with a Nakamichi LX-5 cassette deck and Sennheiser HD 222 or Dynaphase Sixty-A Stanton stereo headphones.

Chapter 3

Results from the Acoustic Study

In this chapter, the results of the acoustic study will be presented. Data from the speaker JS were studied most extensively. Data from the other speakers, for whom fewer tokens were labelled, were examined to confirm findings from the JS data. First, general properties of the vowels will be described. Then, the relative magnitude of the effects of consonantal context, lexical stress, and speech style on vowel variability will be discussed. Interactions among these factors will be examined informally. Finally, the importance to vowel identification of some aspects of the vowel formant trajectories will be examined. Classification by maximum likelihood using Gaussian models of the data will be the objective method of vowel identification.

3.1 General Properties of the Vowels

3.1.1 Formant Midpoints

Plots of each speaker's vowel midpoints in F1-F2 Bark space[1] modelled as two-dimensional Gaussian distributions are shown in Figure 3.1. The ellipses are equal probability contours one standard deviation away from the mean. For comparison, average midpoints of vowels in a /hVd/ context are plotted, both from the speaker and from the large Peterson and Barney (1952) corpus. The speakers for this study show no anomalies. As expected, the male speakers, JS and MP, tend to have lower formant values for each vowel class

[1]Distances on the Bark scale reflect the fact that humans' ability to resolve frequencies decreases on a Hertz scale as frequency increases (Zwicker, 1961).

than the female speakers, RU and EE. For each speaker, the greatest overlap among the vowels studied occurs between /ɛ/ and /ʌ/. Speaker MP's /e/ and /ɪ/ distributions also overlap. Speaker RU's vowel distributions show the least overlap of the three speakers.

3.1.2 Durations

In Figures 3.2 to 3.5, box-plots showing the medians and outliers of the vowel duration distributions for each speaker are shown. (The boxplot is described by Chambers et al., 1983; the boxplots shown were drawn by *S+*, Becker et al., 1988). In Table 3.1, the means and standard deviations of the duration distributions are listed along with the number of tokens. For comparison, average durations for each vowel from Crystal and House (1988), compiled from a large, continuous read speech database from six speakers, are also listed. As expected, the tense vowels /i/ and /e/ tend to be longer than the lax vowels /ɪ/, /ɛ/, and /ʌ/, but the distributions overlap greatly. JS and RU both have outliers in their /i/ distributions. The outliers in JS's data occurred in carrier phrase versions of the words "fatigue" and "fogeys," where a slight pause was inserted after the word. The outliers in RU's data occurred in spontaneous prepausal versions of the words "fatigue" and "seaweed." In all of these cases, the prepausal position of the syllable (which was meant to be avoided in the database) and the voiced consonant closing the syllable caused the vowel to be extremely long compared to the rest of the distribution. Otherwise, the database for the present study shows no anomalies.

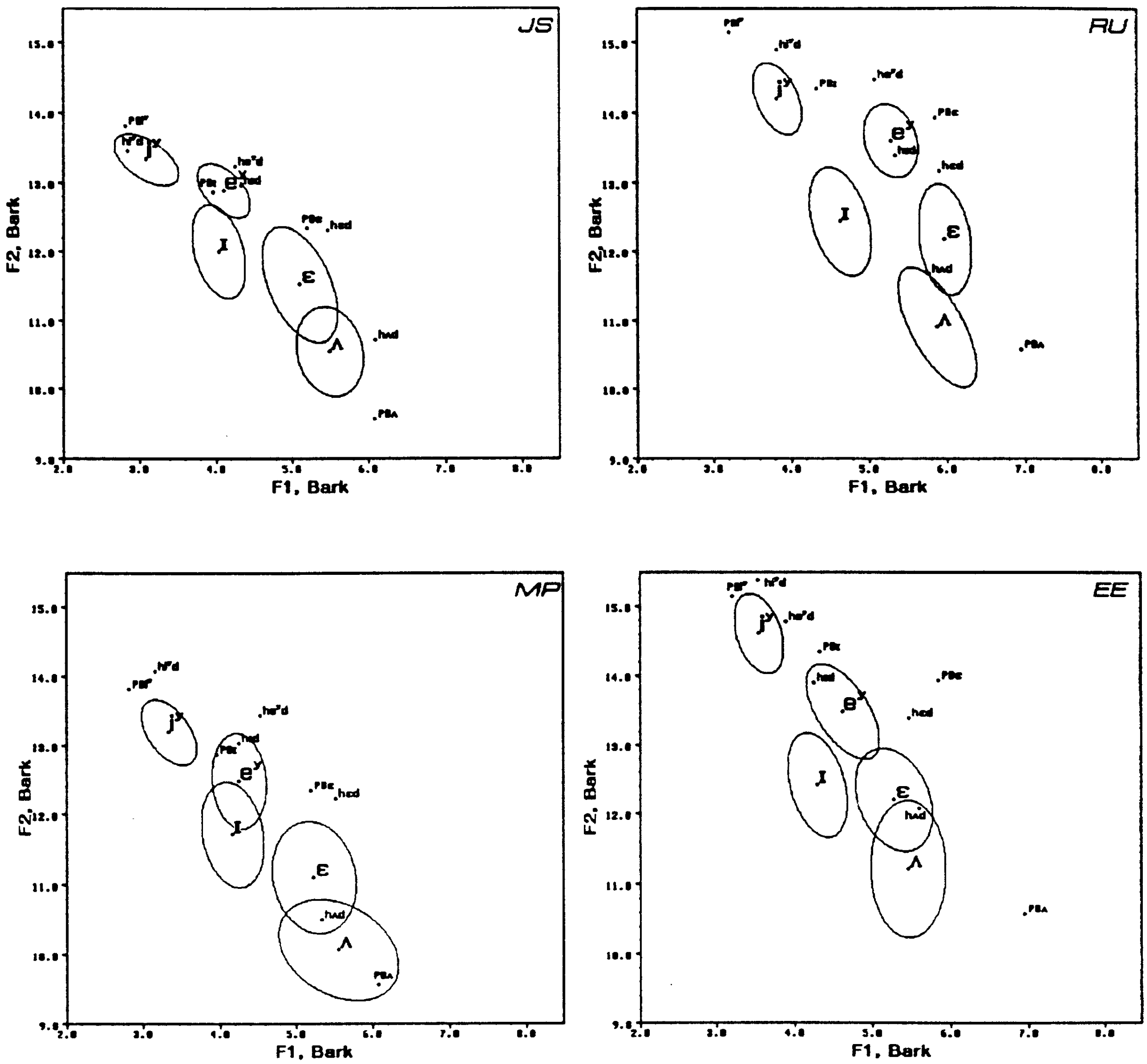

Figure 3.1: F1-F2 plots of all vowels in database for four speakers. Distributions of each speaker's vowel midpoints modelled as two-dimensional Gaussian distributions. Ellipses are equal probability contours one standard deviation away from the mean. Average midpoints of vowels in /hVd/ context also plotted, both from the speaker (labelled "hVd") and from the Peterson and Barney (1952) corpus (labelled "PB"). The number of tokens for each distribution can be found from Table 2.4 by adding the number of occurrences of each vowel for each speaker. Speakers for this study show no anomalies. As expected, the male speakers, JS and MP, have lower formant values for each vowel class than the female speakers, RU and EE.

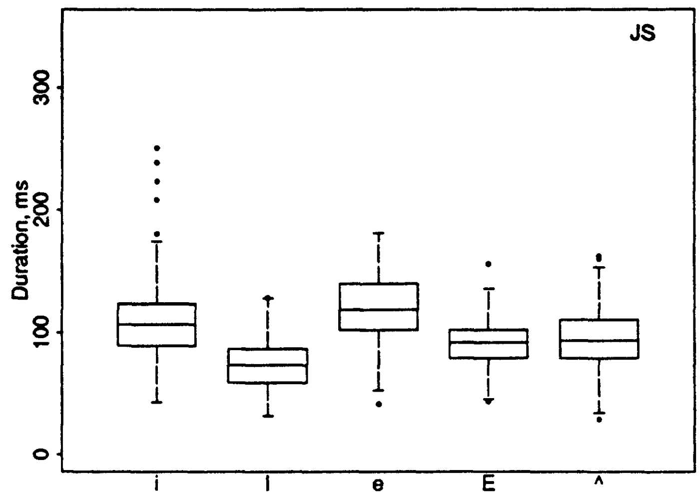

Figure 3.2: Box-plots of durations of all vowels for speaker JS. The upper and lower horizontal lines (called "hinges") forming the rectangle (called "the box") show the limits of the middle 50% of the durations. The horizontal line within the rectangle shows the median. The dotted lines extend to the last points in the distributions which are within 1.5 times the height of the box from the hinges. Dots show points beyond the 1.5 limit.

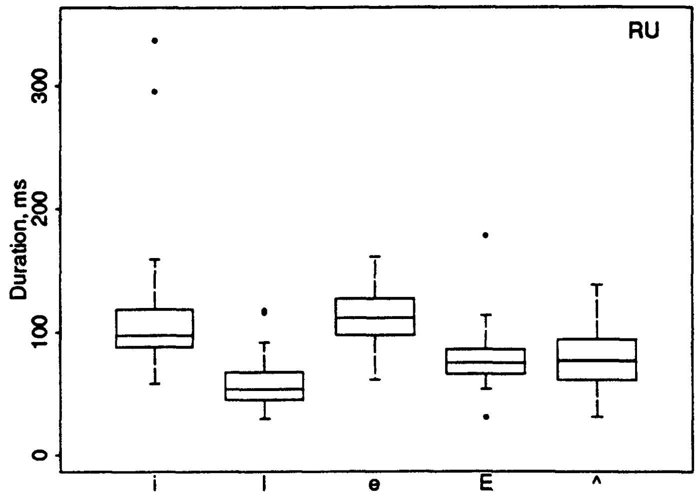

Figure 3.3: Box-plots of durations of all vowels for speaker RU. The upper and lower horizontal lines (called "hinges") forming the rectangle (called "the box") show the limits of the middle 50% of the durations. The horizontal line within the rectangle shows the median. The dotted lines extend to the last points in the distributions which are within 1.5 times the height of the box from the hinges. Dots show points beyond the 1.5 limit.

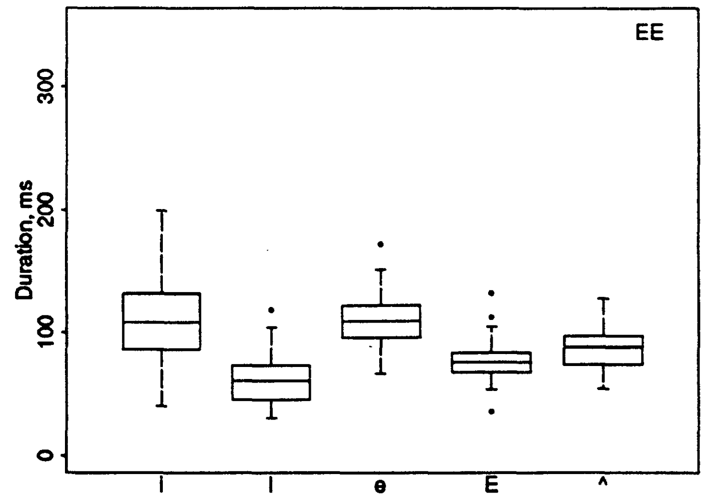

Figure 3.4: Box-plots of durations of all vowels for speaker EE. The upper and lower horizontal lines (called "hinges") forming the rectangle (called "the box") show the limits of the middle 50% of the durations. The horizontal line within the rectangle shows the median. The dotted lines extend to the last points in the distributions which are within 1.5 times the height of the box from the hinges. Dots show points beyond the 1.5 limit.

3.1.3 Formant Trajectories

Parabolas were fit to the middle 50% of each vowel for JS. Only the middle 50% was considered because the regions close to the consonant boundaries contained unsmooth formant movements, presumably due to voiced/unvoiced transitions or rapid movements of articulators for consonant production. The curvature and the location of the extreme point of the parabola was found.

For each vowel, the position of the extremum (maximum or minimum) was described as being before the vowel boundary, in the first third of the vowel, in the second third, in the last third, or after the vowel boundary. (If the extremum was outside the vowel boundaries, the trajectory of the vowel was monotonically increasing or decreasing). The percentage of tokens having each extremum position is shown for F1 and F2 of each vowel class in Figures 3.6 and 3.7.

Previous studies have found that the tense vowels /i/ and /e/ often have an offglide

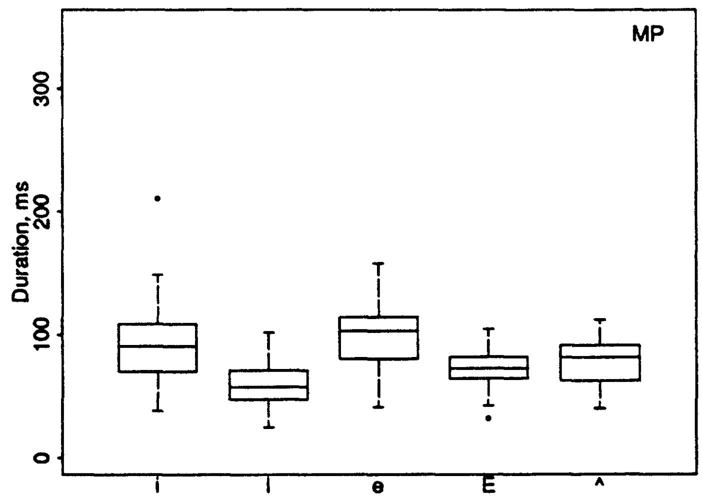

Figure 3.5: Box-plots of durations of all vowels for speaker MP. The upper and lower horizontal lines (called "hinges") forming the rectangle (called "the box") show the limits of the middle 50% of the durations. The horizontal line within the rectangle shows the median. The dotted lines extend to the last points in the distributions which are within 1.5 times the height of the box from the hinges. Dots show points beyond the 1.5 limit.

Table 3.1: Durations in ms of vowels for four speakers (JS, RU, EE, and MP). Data shown as mean $\pm$ standard deviation, with number of tokens (n) in parentheses. The row marked C&H shows average durations for six speakers from Crystal and House, (1988, from their Table XI), for comparison.

	/i/	/ɪ/	/e/	/ɛ/	/ʌ/
JS	110 ± 34 ($n = 170$)	74 ± 20 ($n = 167$)	120 ± 27 ($n = 220$)	91 ± 19 ($n = 162$)	94 ± 23 ($n = 135$)
RU	111 ± 51 ($n = 45$)	59 ± 20 ($n = 48$)	112 ± 23 ($n = 61$)	79 ± 22 ($n = 45$)	78 ± 26 ($n = 34$)
EE	112 ± 34 ($n = 45$)	61 ± 19 ($n = 50$)	109 ± 20 ($n = 62$)	76 ± 16 ($n = 46$)	87 ± 19 ($n = 33$)
MP	93 ± 33 ($n = 39$)	59 ± 17 ($n = 46$)	98 ± 26 ($n = 59$)	72 ± 16 ($n = 41$)	78 ± 20 ($n = 32$)
C&H	107 ± 43 ($n = 272$)	60 ± 25 ($n = 674$)	133 ± 49 ($n = 196$)	82 ± 38 ($n = 358$)	88 ± 37 ($n = 293$)

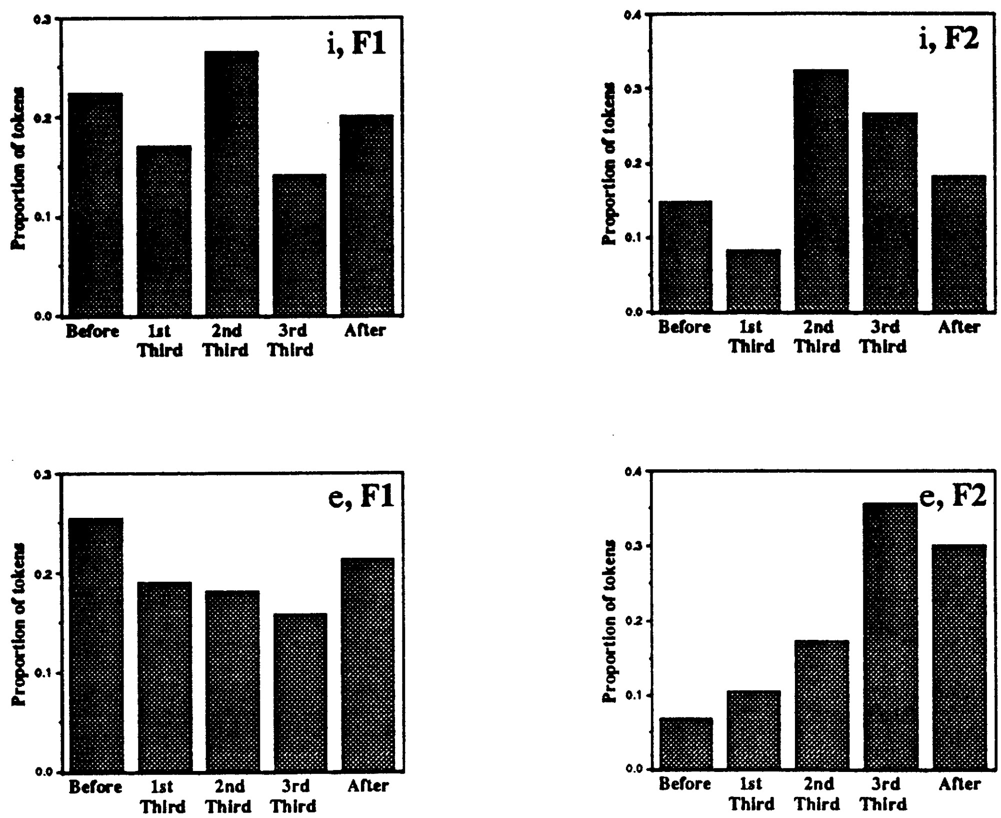

Figure 3.6: Characteristics of F1 and F2 trajectories of JS tense vowels. Proportion of tokens with extremum before vowel boundary, in first third, in second third of vowel, in third third of vowel, or after vowel boundary.

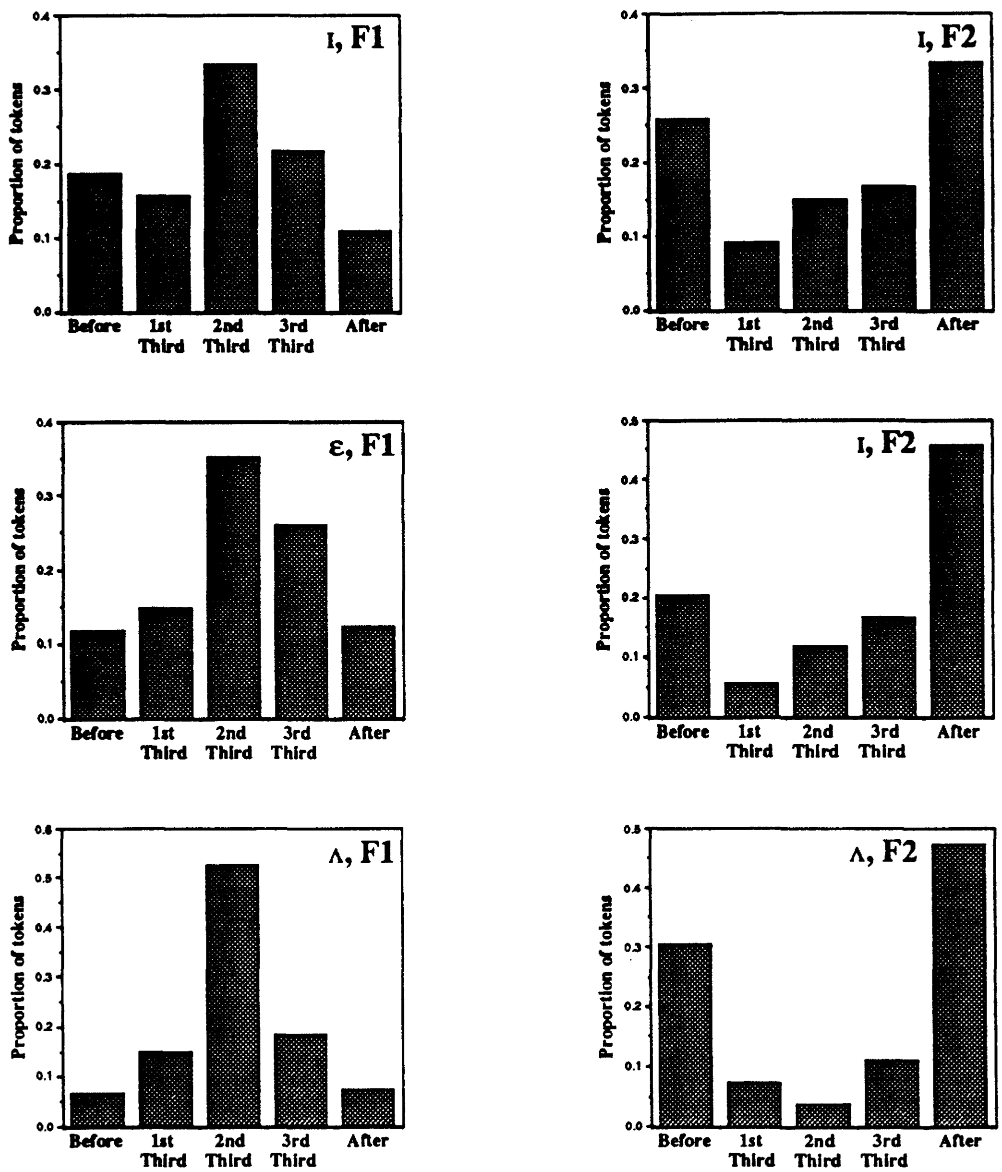

Figure 3.7: Characteristics of F1 and F2 trajectories of JS lax vowels. Proportion of tokens with extremum before vowel boundary, in first third of vowel, in second third of vowel, in third third of vowel, or after vowel boundary.

toward /**y**/, whereas the lax vowels have an offglide toward /ə/ or no offglide (see, for example, Lehiste and Peterson, 1961; Stevens et al., 1966). These differences are reflected in the bar graphs. The F1 trajectories of the lax vowels tend to have an extreme point in the middle of the vowel, whereas the extreme points of the tense vowels are more evenly distributed. The F2 trajectories of the tense vowel /**e**/ tend to have an extreme point in the last third of the vowel, suggesting the presence of the /**y**/ offglide, whereas the F2 trajectories of the lax vowels tend to be monotonically increasing or decreasing, presumably due to the consonant context. The /**y**/ offglide is not as apparent for /i/ as it is for /**e**/.

A table of data for the individual tokens of each speaker can be found in Appendix C.

3.2 Effects of Consonant Context, Lexical Stress, and Speech Style on Vowel Variability

3.2.1 Effects on Formant Midpoints

Previous studies (Stevens and House, 1963; Lehiste, 1962) have investigated the effect of consonant context on the midpoint F1 and F2 frequencies of vowels. The effect is described as a shift of the midpoint on an F1-F2 plot relative to the position of the midpoint in some reference context. Similarly, midpoint shifts have been described for unstressed vowels relative to stressed vowels and vowels in running speech relative to isolated vowels (e.g., Delattre, 1969; Koopmans-van Beinum, 1980). The data of the present study were analyzed in a similar fashion. For each factor, a reference was chosen. For the consonant contexts, the reference was the /**d**/ context, for lexical stress, the reference was primary stress, and for speech style, the reference was the read-story style. Then, the shifts in the means of the vowel midpoints were examined for each speaker. For example, it was found that the mean F1 of /ɪ/ tokens preceded by /**w**/ was higher than the mean F1 for /ɪ/ tokens preceded by /**d**/, the reference context, for each of the four speakers. Because of possible measurement error and the small number of speakers, it was decided to note only the general characteristics of the shifts rather than averaging shift sizes across speakers.

Figures 3.8 through 3.11 show JS's vowels divided according to consonant context, lexical stress, and speech style, and modelled as two-dimensional Gaussian distributions. The ellipses are equal probability contours one standard deviation away from the mean. A different subset of JS's full vowel set was taken for each plot in order to balance the factors. For example, there is the same proportion of primary-stressed to secondary-stressed vowels in each of the /i/ distributions in the consonant context plot. In addition, the nonsense words were excluded from the lexical stress plot because the speaker seemed inconsistent in stressing nonsense syllables meant to receive secondary stress. The spontaneous tokens were omitted from all plots except Figure 3.11, because it was not possible to balance the representation of stress and context. For Figure 3.11, the separate plot showing only data from the read story and spontaneous speech, tokens were thrown out of the full read vowel set if they did not have a spontaneous counterpart. Table 3.2 shows the number of tokens in each JS vowel distribution. Plots from the three other speakers are shown in Appendix B.

The directions of the shifts of the F1-F2 midpoint means are summarized in Tables 3.3 to 3.5. Shifts of the centroids are coded as + (meaning the mean value was higher in frequency than the reference mean) or - (meaning the mean value was lower in frequency than the reference mean) for each of the three factors and for each speaker. Figures 3.12 to 3.14 show schematized plots of shifts which were consistent for at least three out of the four speakers. The arrows in the figures are highly stylized, all having the same length and limited in direction to a multiple of 45°. They do not show details of the direction or magnitude of the shifts. If no shift is indicated in the figure, it means that any shift seen in the data was not consistent across speakers. A vertical or horizontal arrow indicates that a shift was only consistent for one of the formants.

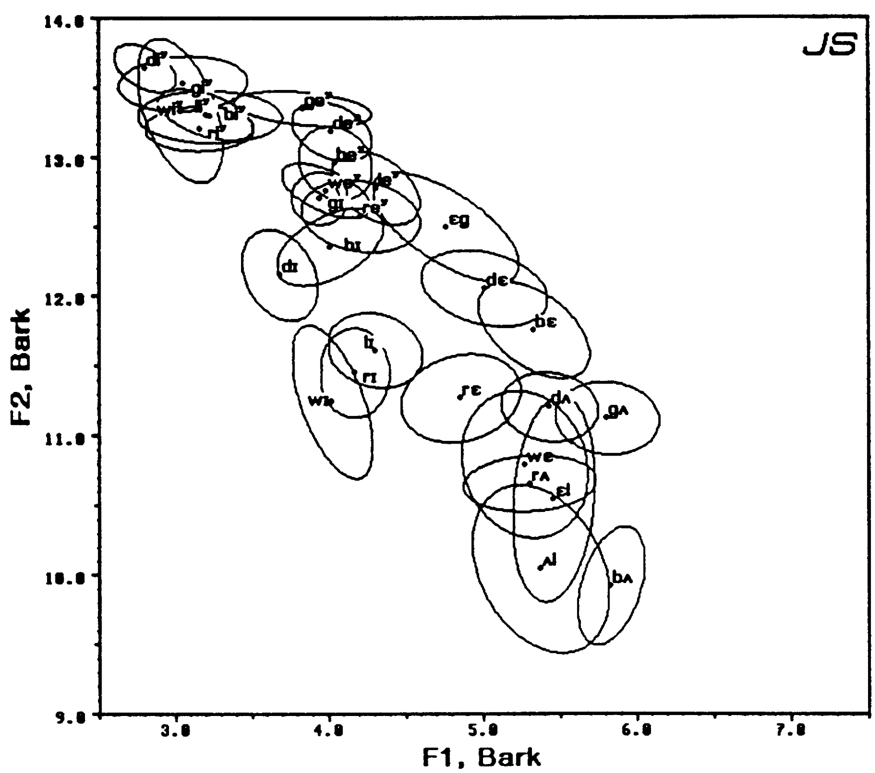

Figure 3.8: F1-F2 plots of midpoints for JS vowel tokens grouped according to consonantal context. Distributions modelled as two-dimensional Gaussians. Ellipses are equal-probability contours one standard deviation from the mean.

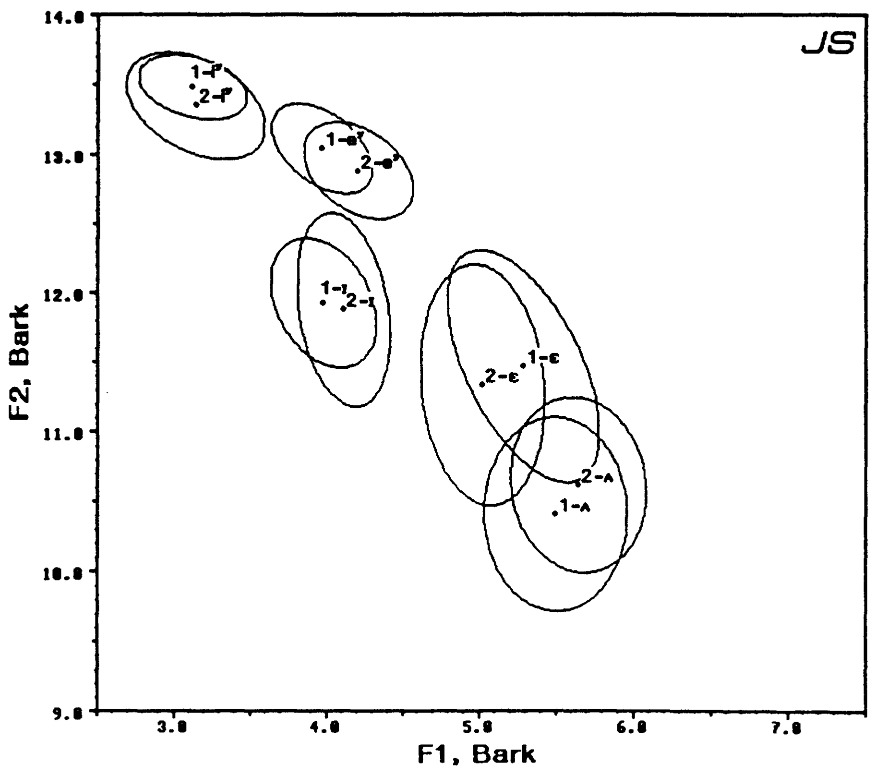

Figure 3.9: F1-F2 plots of midpoints for JS vowel tokens grouped according to level of lexical stress. Distributions modelled as two-dimensional Gaussians. Ellipses are equal-probability contours one standard deviation from the mean.

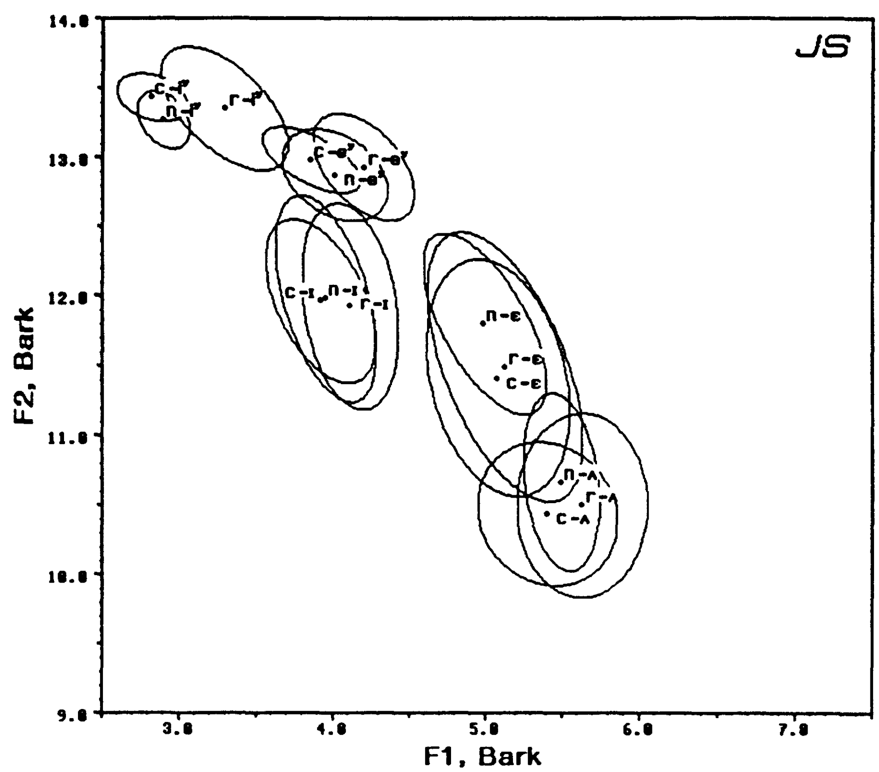

Figure 3.10: F1-F2 plots of midpoints for JS vowel tokens grouped according to speech style. Distributions modelled as two-dimensional Gaussians. Ellipses are equal-probability contours one standard deviation from the mean. Key for labels of means: n = nonsense words, c = real words in carrier phrase, r = read.

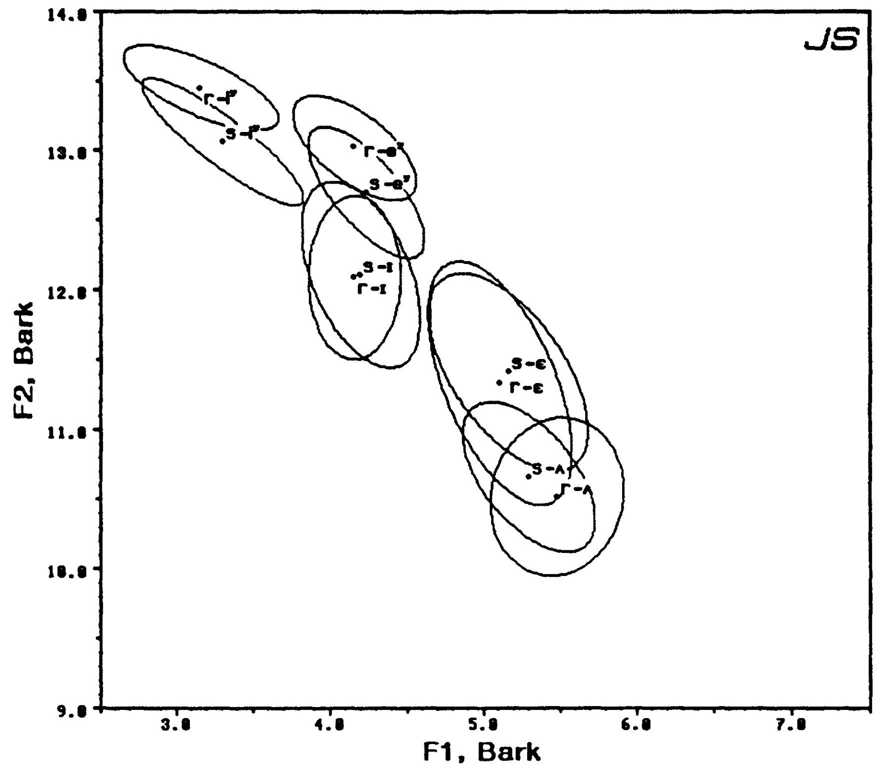

Figure 3.11: F1-F2 plots of midpoints for JS vowel tokens grouped according to read or spontaneous style. Each read token has a corresponding spontaneous token. Distributions modelled as two-dimensional Gaussians. Ellipses are equal-probability contours one standard deviation from the mean.

Table 3.2: Number of tokens in distributions in each JS F1-F2 plot.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	42	42	42	42	35
	sec.	42	42	42	42	35
context	b-init.	18	18	18	18	18
	d-init.	18	18	18	18	18
	g-init.	18	18	18	0	18
	g-fin.	0	0	0	18	0
	w-init.	18	18	18	18	0
	r-init.	18	18	18	18	18
	l-init.	18	18	18	0	0
	l-fin.	0	0	0	18	18
style	nons.	30	28	28	28	24
	car.ph.	30	28	28	28	24
	read	75	70	70	70	60
style (read-sp.)	read	15	11	29	21	19
	spont.	15	11	29	21	19

The centralization effect found in previous studies is seen in the figures for lexical stress and speech style. However, Tables 3.3 to 3.5 show that the shifts are small and often inconsistent across speakers. For example, shifts due to style are inconsistent across speakers in F1 for /ɪ/ and /i/ and in F2 for /ɛ/ and /ʌ/. Although the general direction of the shift going from primary stress to secondary stress is toward the center of the vowel quadrilateral, it is unclear exactly where the "center" is. Therefore, it is difficult to explain the "centralization" effect in articulatory terms, except to assume (as in previous studies) that the more "relaxed" condition results in a generally less extreme vowel articulation.

The context assimilation effect, also found in previous studies, is seen in Figure 3.12 for consonant context. The shifts due to consonant context tend to be larger and more consistent across speakers than the other shifts, particularly for the liquid and glide contexts. The F1-F2 plot for JS in Figure 3.8 shows that the shift size for front lax vowels is on the order of one Bark. Data for the other speakers are similar. Directions and sizes of the shifts in F2 are generally in accordance with previous findings by Lehiste (1962) and Stevens and House (1963), even though the previous studies examined isolated words and words in carrier phrases, whereas the present study included a read story. The consonants /w/, /r/, and (usually, in American English) /l/ are produced with a backed tongue position, and would therefore be expected to lower F2. Velars such as /g/ have both a front and back allophone which generally assimilate to the backness of the adjacent vowel. The front allophone of /g/ is presumably causing the increase in F2 for /gi/, /gɪ/, and /ge/, and the back allophone is presumably causing the decrease in F2 for /gʌ/. However, some of the shifts are contrary to expectations. For example, the /w/-initial context causes a positive shift in F1 relative to the /d/ context, even though /w/ is articulated with a high tongue position and would therefore be expected to cause F1 to decrease. Shifts in F1 may be less reliable than shifts in F2 because of measurement error, which affect F1 more than F2 because of the smaller shifts in F1 on a Hertz scale.

Table 3.3: Directions of shifts of F1-F2 midpoint means due to consonant context for speakers JS, RU, EE, and MP. Reference context is /**d**/-initial. For example, the + in the /**bi**/, JS, F1 cell means that the mean F1 midpoint for JS's /**i**/ in /**bi**/ is greater than that for /**i**/ in /**di**/. /**l**/-context for /**ɛ**/ and /**ʌ**/ and /**g**/-context for /**ɛ**/ are final contexts. Parentheses indicate shifts of less than .2 Bark.

		JS		MP		RU		EE	
Vowel	Context	F1	F2	F1	F2	F1	F2	F1	F2
/i/	b	+	-	+	(-)	+	+	+	(-)
	d	0	0	0	0	0	0	0	0
	g	+	(-)	(-)	+	(-)	+	(+)	+
	w	+	-	(-)	(-)	+	+	(-)	(+)
	r	+	-	(+)	-	0	0	+	-
	l	+	-	0	-	+	-	(+)	(-)
/ɪ/	b	+	+	(-)	(-)	(+)	+	+	+
	d	0	0	0	0	0	0	0	0
	g	+	+	(-)	(-)	(+)	+	(+)	+
	w	+	-	(-)	-	+	-	+	-
	r	+	-	(+)	-	(+)	-	+	-
	l	+	-	(-)	-	+	-	+	-
/e/	b	(+)	-	+	(+)	(+)	-	+	(-)
	d	0	0	0	0	0	0	0	0
	g	(-)	(+)	(+)	+	(-)	+	(+)	+
	w	(-)	-	+	-	(+)	-	+	-
	r	(+)	-	+	-	(+)	-	+	-
	l	+	-	+	-	(-)	-	+	-
/ɛ/	b	+	-	(-)	-	+	-	+	+
	d	0	0	0	0	0	0	0	0
	-g	-	+	(-)	+	+	+	-	+
	w	+	-	+	-	+	-	(+)	-
	r	(-)	-	-	-	0	-	-	-
	-l	+	-	(-)	-	+	-	+	-
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	d	0	0	0	0	0	0	0	0
	g	+	(-)	(+)	-	(+)	-	(+)	+
	w								
	r	(-)	-	-	-	-	(+)	-	-
	-l	(-)	-	(+)	-	(+)	-	-	-

Table 3.4: Directions of shifts of F1-F2 distribution centroids due to lexical stress for speakers JS, RU, EE, and MP. Reference is primary stress. For example, the + in the Sec.,/i/, JS, F1 cell means that the mean F1 midpoint for JS's secondary-stressed /i/'s is greater than that for primary-stressed /i/'s. Parentheses indicate shifts of less than .2 Bark.

		JS		MP		RU		EE	
Vowel	Stress	F1	F2	F1	F2	F1	F2	F1	F2
/i/	Prim.	0	0	0	0	0	0	0	0
	Sec.	(+)	(-)	-	-	+	-	(-)	(-)
/ɪ/	Prim.	0	0	0	0	0	0	0	0
	Sec.	(+)	(-)	(+)	(+)	+	(-)	(-)	(+)
/e/	Prim.	0	0	0	0	0	0	0	0
	Sec.	+	(-)	(+)	-	(-)	(-)	(+)	-
/ɛ/	Prim.	0	0	0	0	0	0	0	0
	Sec.	-	(-)	+	-	-	+	-	(-)
/ʌ/	Prim.	0	0	0	0	0	0	0	0
	Sec.	(+)	+	-	(-)	-	+	-	+

Table 3.5: Directions of shifts of F1-F2 distribution centroids due to speech style for speakers JS, RU, EE, and MP. Reference style is "read" (full set for carrier phrase, small set for spontaneous speech). For example, the + in the Spont.,/i/, JS, F1 cell means that the mean F1 midpoint for JS's spontaneous /i/'s is greater than that for the read /i/'s. Parentheses indicate shifts of less than .2 Bark.

		JS		MP		RU		EE	
Vowel	Style	F1	F2	F1	F2	F1	F2	F1	F2
/i/	Car.Ph.	-	(+)	(+)	+	(-)	+	-	+
	Read	0	0	0	0	0	0	0	0
	Spont.	(+)	-	(-)	(+)	(-)	(+)	-	(+)
/ɪ/	Car.Ph.	(-)	(+)	+	+	(-)	(-)	(-)	(-)
	Read	0	0	0	0	0	0	0	0
	Spont.	(+)	(+)	(+)	(-)	(-)	-	(-)	(-)
/e/	Car.Ph.	-	(+)	+	(+)	(-)	(-)	-	+
	Read	0	0	0	0	0	0	0	0
	Spont.	(+)	-	(+)	(+)	(+)	-	(-)	-
/ɛ/	Car.Ph.	(-)	(-)	(+)	-	-	(+)	-	(+)
	Read	0	0	0	0	0	0	0	0
	Spont.	(+)	(+)	+	(+)	(-)	(-)	(-)	(+)
/ʌ/	Car.Ph.	-	(-)	(+)	(-)	-	(+)	(-)	(-)
	Read	0	0	0	0	0	0	0	0
	Spont.	(-)	(+)	+	(-)	(-)	(-)	-	-

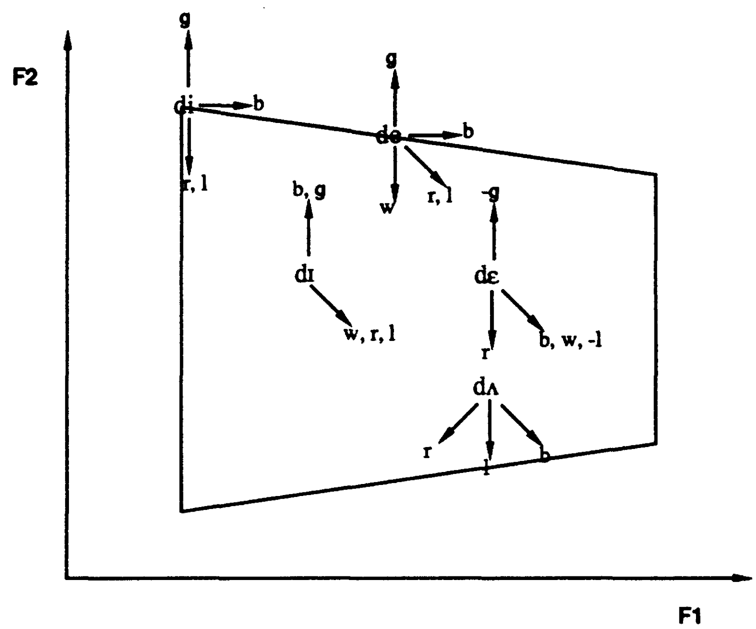


Figure 3.12: Schematized plots of F1-F2 shifts due to consonant context. The arrows in the figures are highly stylized and do not show details of the direction or magnitude of the shifts. If no shift is indicated in the figure, it means that any shift seen in the data was not consistent across speakers. A vertical or horizontal arrow indicates that a shift was only consistent for one of the formants. A shift was considered consistent if all speakers showed a shift in the same direction with two out of four showing a shift of more than .2 Bark, or if three out of four speakers showed a shift of more than .2 Bark in the same direction. The box is a schematized vowel quadrilateral.

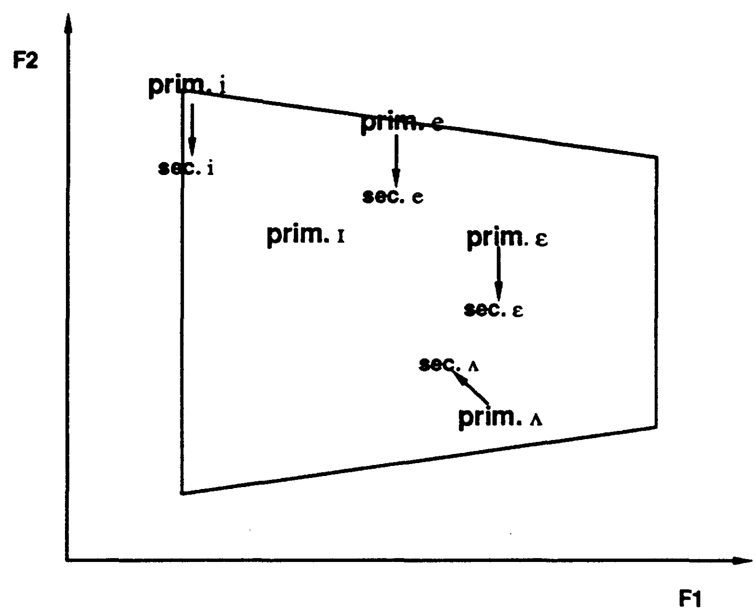


Figure 3.13: Schematized plots of F1-F2 shifts due to lexical stress. The arrows in the figures are highly stylized and do not show details of the direction or magnitude of the shifts. If no shift is indicated in the figure, it means that any shift seen in the data was not consistent across speakers. A vertical or horizontal arrow indicates that a shift was only consistent for one of the formants. A shift was considered consistent if all speakers showed a shift in the same direction with two out of four showing a shift of more than .2 Bark, or if three out of four speakers showed a shift of more than .2 Bark in the same direction. The box is a schematized vowel quadrilateral.

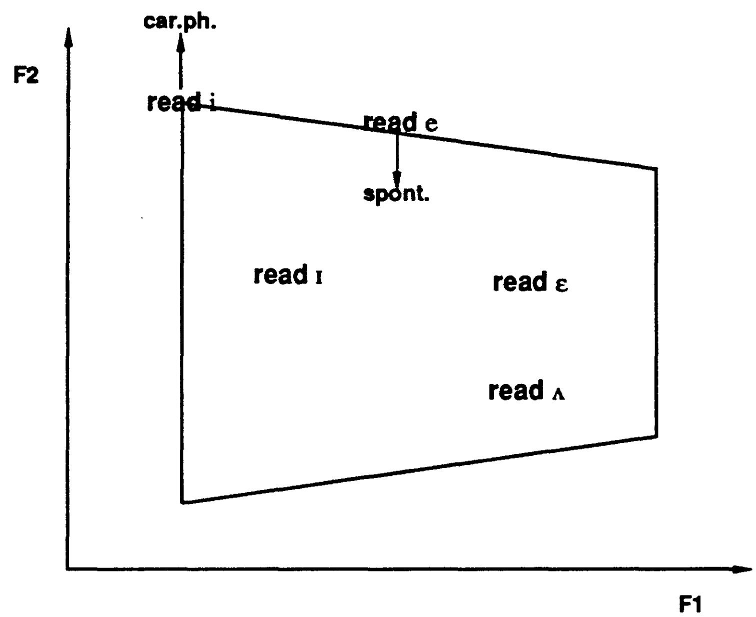


Figure 3.14: Schematized plots of shifts due to speech style. The arrows in the figures are highly stylized and do not show details of the direction or magnitude of the shifts. If no shift is indicated in the figure, it means that any shift seen in the data was not consistent across speakers. A vertical or horizontal arrow indicates that a shift was only consistent for one of the formants. A shift was considered consistent if all speakers showed a shift in the same direction with two out of four showing a shift of more than .2 Bark, or if three out of four speakers showed a shift of more than .2 Bark in the same direction. The box is a schematized vowel quadrilateral.

Relative Magnitude of Effects

The effects of consonant context, lexical stress, and speech style have been examined separately in previous studies. The corpus used for the present study is well-controlled with respect to all three factors and therefore allows comparison of these effects.

In Figure 3.15, some examples of minimum pairs are shown. All spectrograms show the vowel /ɛ/. The top pair of spectrograms shows a minimum pair in the factor consonant context, the middle pair in lexical stress, and the lower pair in speech style. Comparison of the formant trajectories suggests that consonant context affects the vowel formant frequencies more than either of the other two factors.

The effect of the factors on the midpoint formant frequencies, a simple (though incomplete) characterization of the vowel, will be examined more closely. From Figures 3.8 to 3.11, it can be seen that different consonant contexts shift the vowel midpoint distributions in F1-F2 space more than lexical stress (primary and secondary) or speech style (from nonsense words to spontaneous speech). Plots of the data from the three other speakers, shown in Appendix B, are similar.

To quantify the shifting of the distributions from the effect of the factors, the Fisher Criterion was calculated. The Fisher Criterion is the ratio of a measure of the distance between the centroids of the Gaussian models to a measure of the scatter of the model (Duda and Hart, 1973). Figure 3.16 is a bar graph showing the maximum distance between any two distributions within a vowel class for each F1-F2 plot for JS. The maximum sum of distances from nonsense to read and read to spontaneous is shown for speech style. The distance is greatest among the vowel distributions when the vowels are grouped according to their consonant contexts. The great distance between vowels in different contexts is even more apparent if F3 is taken into account as well as F1 and F2. In Table 3.6, the Fisher Criterion distances for the other speakers are shown. (Some of the values are very high because the small number of tokens for some distributions leads to very small variances.) For each speaker and each vowel class, the distances between distributions within a vowel class are greatest for the distributions divided by consonant context.

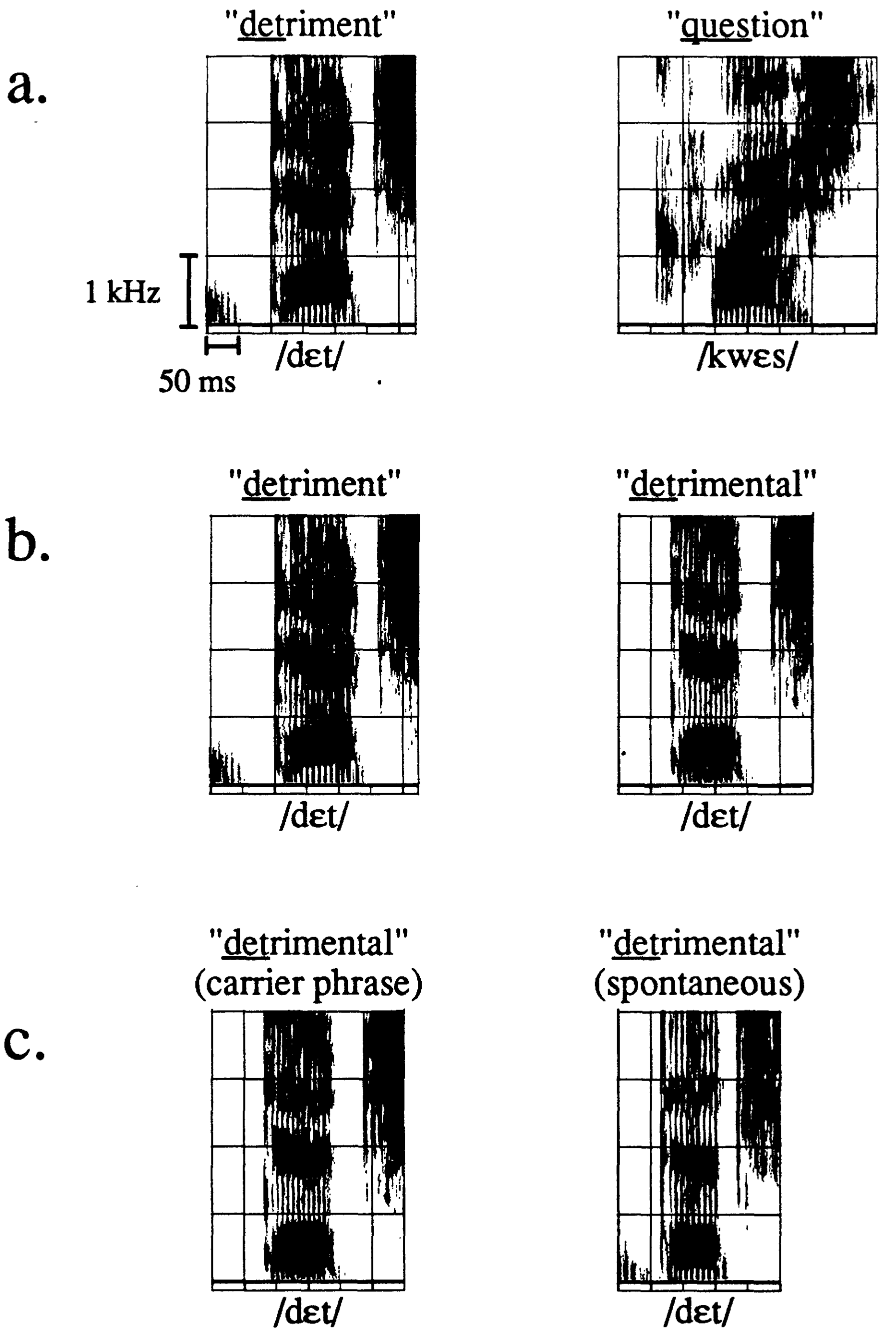


Figure 3.15: Examples of minimum pairs in consonant context, level of lexical stress, and speech style. The vowel /ɛ/ is shown in each case. Row **a.** shows the /ɛ/ vowels in "detriment" and "question," a minimum pair in context. Row **b.** shows the /ɛ/ vowels in "detriment" and "detrimental," a minimum pair in stress. Row **c.** shows the /ɛ/ vowels in "detriment" spoken in a carrier phrase and spontaneously, a minimum pair in style.

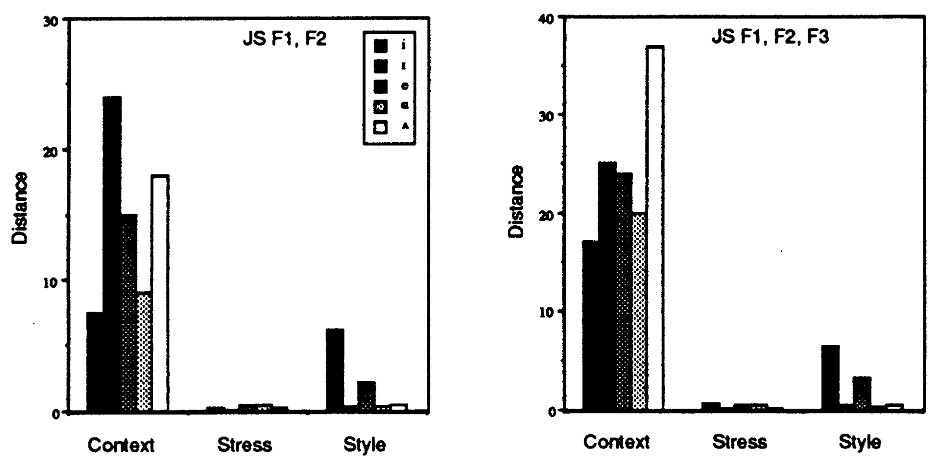


Figure 3.16: Maximum Fisher Criterion distance for JS vowel midpoint distributions (F1, F2 or F1, F2, F3). For example, the leftmost bar in the top graph is the distance between the distributions of F1-F2 midpoints of /**bi**/ and /**wi**/, which are furthest apart among the /**i**/ distributions when /**i**/ tokens are grouped according to context.

Table 3.6: Maximum Fisher Criterion distance between any two distributions within each set of vowels having the same phonemic label. Vowels having the same phonemic label are divided according to their consonant context, lexical stress, or speech style, and means and standard deviations of the smaller distributions are computed. Style data are from carrier phrase/read/spontaneous data for RU, EE, and MP and from sum of maxima for nonsense/carrier phrase/read and read/spontaneous for JS.

		Context		Stress		Style	
		F1,F2	F1,F2,F3	F1,F2	F1,F2,F3	F1,F2	F1,F2,F3
RU	/i/	27	27	1.1	2.1	.40	.62
	/ɪ/	20	53	.57	.61	.38	.41
	/e/	83	230	.053	.16	.40	1.1
	/ɛ/	38	82	.34	.67	1.0	1.0
	/ʌ/	28	74	.67	.86	.65	.66
EE	/i/	30	30	.56	.84	6.3	6.3
	/ɪ/	74	340	.065	.076	.040	.20
	/e/	7.7	12.8	.79	.86	.59	.59
	/ɛ/	11	11	.66	.66	.44	.44
	/ʌ/	13	17	.59	.63	1.1	1.1
MP	/i/	30	43	.97	.97	2.5	.36
	/ɪ/	170	170	.12	.21	6.7	13
	/e/	55	97	.14	.18	2.0	2.1
	/ɛ/	19	96	.56	.59	.33	2.6
	/ʌ/	62	100	.20	1.0	.17	1.8
JS	/i/	7.5	17	.19	.58	6.1	6.5
	/ɪ/	24	25	.16	.22	.36	.52
	/e/	15	24	.52	.55	2.2	3.2
	/ɛ/	9.0	20	.51	.52	.32	.37
	/ʌ/	18	37	.22	.24	.46	.52

The maximum distance between any two out of a number of distributions is likely to increase with an increasing number of distributions. A greater number of consonant contexts was examined than levels of stress or speech style. Therefore, it can be argued that the greater maximum distance between consonant context distributions arises by chance. To quantify the separation among distributions while accounting for the difference in number of distributions for each factor, a multivariate analysis of variance (MANOVA, Johnson and Wichern, 1988; *S+* software package used to calculate p values, Becker et al., 1988) was calculated. The MANOVA statistic (Bartlett's statistic) is similar to the Fisher Criterion but includes a factor which depends on the number of distributions within each vowel class. Effectively, when there are more distributions, the distance must be greater for the MANOVA statistic to reach the same level of significance as for a set of fewer distributions. The MANOVA was calculated on the intersection of the vowel sets used for the F1-F2 plots. Table 3.7 lists the values of $(1-p)$ for each speaker, each vowel class, and each factor dividing the data, where p is the smallest level of significance for which the null hypothesis could be rejected. The quantity $(1-p)$ is the probability that the centroids within the vowel class arise from different distributions, that is, that shifts in the centroids do not arise by chance alone. The table shows that the distributions are significantly different to a level of .001 for most of the vowel classes for all speakers when divided by consonant context, though significant differences do occur elsewhere.

Since a large number of independent MANOVAs are computed, it cannot be claimed that all the statistical differences are significant at the level of the specified p value. Rather, the probability of all shifts in centroids arising from different distributions is the product of the $(1-p)$ values obtained for each MANOVA. (This is known as the "multiple comparison problem.") However, though the representation of the data as MANOVA statistics has some problems, this representation, as well as the plots of the distributions and the Fisher Criterion measure all suggest that consonant context shifts a vowel's midpoint more than primary and secondary lexical stress for the different speech styles studied.

It may be argued that the convention for setting the boundaries between liquids or glides and vowels, discussed in Chapter 2, tends to result in a vowel midpoint which is closer to the consonant than other commonly used conventions. For the present study, a boundary

Table 3.7: Values of $(1-p)$ from MANOVA, i.e., probability that the true means of formant midpoints (F1, F2, F3) of vowels from different context, stress, or style conditions are different. For example, the .969 in the RU, /i/, Context cell means that the probability is .969 that /i/'s in at least one of the contexts (e.g., /**bi**/) have mean formant midpoint frequencies which are different from /i/'s in other contexts. MANOVA performed on same set of vowels for context, stress, and style. Tokens in "style (read/spont.)" set are matched pairs of read-story and spontaneous versions. Number of tokens (n and n_s) noted for each set. The JS half-pts. row shows data from the alternative labelling procedure.

		n	Context	Stress	Style	n_s	Style(read/spont.)
RU	/i/	24	.969	.965	.415	33	.618
	/ɪ/	24	1.000	.591	.001	36	.532
	/e/	24	1.000	.148	.111	51	.990
	/ɛ/	24	1.000	.637	.750	39	.910
	/ʌ/	20	1.000	.641	.176	30	.667
EE	/i/	24	.774	.730	.978	33	1.000
	/ɪ/	24	1.000	.577	.004	42	.320
	/e/	24	.990	.736	.879	54	.924
	/ɛ/	24	1.000	.628	.126	42	.731
	/ʌ/	20	1.000	.510	.024	27	.675
MP	/i/	24	.829	.785	.783	15	.839
	/ɪ/	24	1.000	.206	.982	30	1.000
	/e/	24	1.000	.170	.979	45	.991
	/ɛ/	24	1.000	.583	.156	27	.835
	/ʌ/	20	.999	.717	.001	24	.799
JS	/i/	84	1.000	.987	1.000	30	.987
	/ɪ/	84	1.000	.773	.391	22	.143
	/e/	84	1.000	.984	1.000	58	1.000
	/ɛ/	84	1.000	.980	.014	42	.160
	/ʌ/	70	1.000	.732	.257	38	.396
JS	/i/	84	1.000	.988	1.000	30	.990
half-	/ɪ/	84	1.000	.484	.300	22	.044
pts.	/e/	84	1.000	1.000	1.000	58	1.000
	/ɛ/	84	1.000	.982	.043	42	.042
	/ʌ/	70	1.000	.658	.160	38	.365

was only set if the amplitudes of higher formants rose suddenly in the vocalic portion of the signal. If no boundary was set, the entire vocalic portion, from the apparent point of maximum closure due to the liquid or glide to the boundary of the consonant on the other side of the vowel, was labelled as the vowel. Most conventions would assign part of the vocalic portion to the liquid or glide. Therefore, most conventions would result in a midpoint which is further from the maximum closure of the liquid or glide than the convention used in this study. To check whether the large shifts in midpoints among different consonant contexts arises from this segmentation convention, a second convention was tested for speaker JS. An example of the second segmentation convention is shown in Figure 3.17. For the liquid or glide contexts, the region including the vowel between the labelled maximum closure and the alveolar boundary was found. Then, the boundary between the liquid or glide and vowel was set halfway into this region. The midpoint of the vowel would then be set halfway into the newly determined vowel region. The MANOVAS were performed on the new data for JS, and the results, shown at the bottom of Table 3.7, do not differ appreciably from those from the first segmentation convention.

Interactions Among Factors

In the previous section, it was shown that the means of the overall distributions of JS tokens grouped according to their different levels of lexical stress or speech styles do not differ greatly. Now it is asked whether the effects of lexical stress or speech style are greater for a subset of the data, which would be the case if the factors interact. Interactions among the three factors, consonant context, lexical stress, and speech style, will now be examined informally for speaker JS.

It may be hypothesized that the formant frequencies of primary- and secondary-stressed vowels are more different in casual speech styles than in formal speech styles. That is, secondary stress and the spontaneous speech style may interact to produce more reduction of the vowel than the sum of each of their effects alone. If this were the case, the overall distributions shown in Figure 3.9 may not show the reduction, since one style, speech from a read story, dominated the database. (In fact, no spontaneous tokens were included

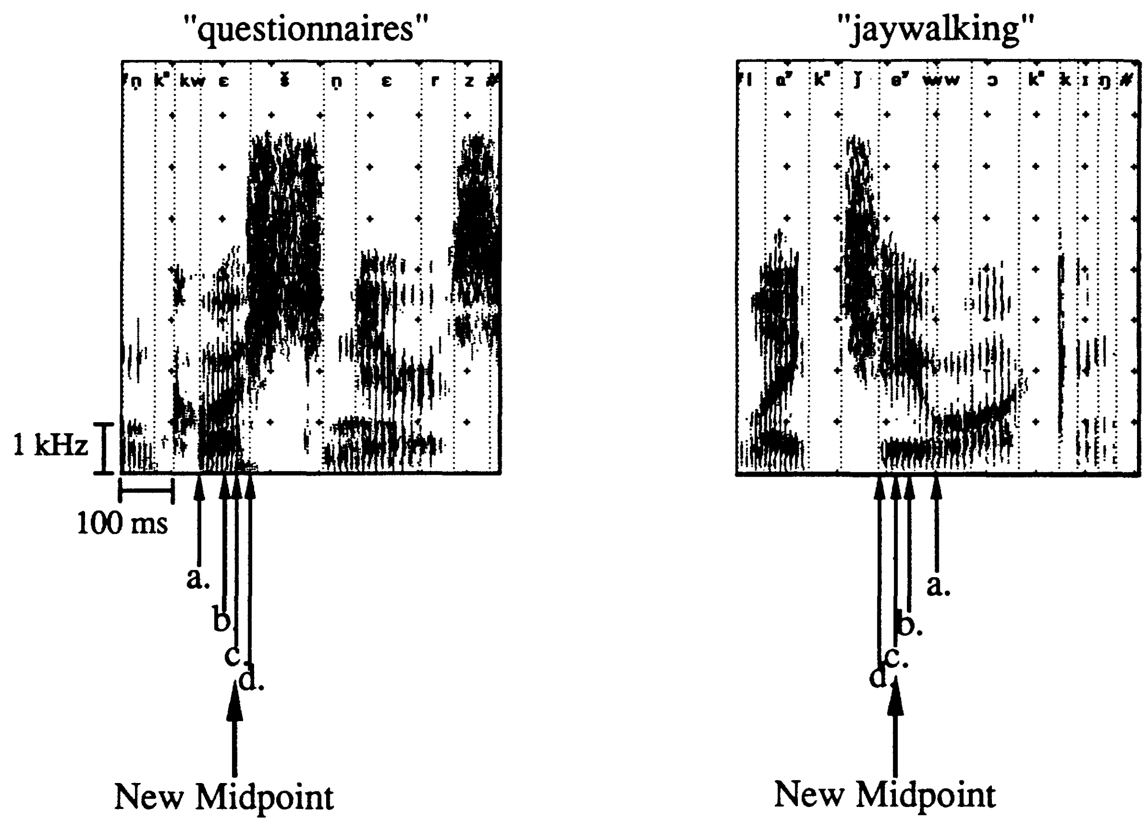


Figure 3.17: Examples of an alternative segmentation convention for boundaries between liquids or glides and vowels. The words are "questionnaires" and "jaywalking." Boundaries shown are from the original segmentation. For "questionnaire," the original segmentation may assign more of the /**wɛ**/ region to the /**ɛ**/ than other frequently-used conventions, resulting in the choice of a vowel midpoint which is more influenced by the /**w**/. The alternative convention chooses the midpoint further away from the /**w**/. This alternative convention places the boundary between /**w**/ and /**ɛ**/ (**b.**) halfway into the region between the maximum closure for /**w**/ (**a.**) and the consonant boundary (**d.**). The new vowel midpoint is halfway into the new vowel region (**c.**). The same points are shown in the example of "jaywalking."

in the averages for Figure 3.9, because it was not possible to balance the representation of stress and context in the spontaneous set of tokens.) Therefore, it would be instructive to plot primary- and secondary-stressed spontaneous vowel tokens, as in Figure 3.18. For each vowel phoneme are shown the F1-F2 means of four groups: the read, primary-stressed vowels; the read, secondary-stressed vowels; the spontaneous, primary-stressed vowels; and the spontaneous, secondary-stressed vowels. All of JS's spontaneous tokens were included in the averages for spontaneous speech. Only those tokens from the read story which came from words also present in the spontaneous set were included in the read speech averages. The number of tokens is small, ranging from 11 to 30 tokens per vowel phoneme for each style (see Table 2.4 in Chapter 2 and Appendix C). Therefore, conclusions from these data must be drawn with caution.

In Figure 3.18, an arrow points from the mean of the primary-stressed group to the mean of the secondary-stressed group for each speech style. Therefore, the length of the arrow indicates the magnitude of the effect of stress on vowel midpoints for each speech style. There does not seem to be a strong tendency for spontaneous vowels to shift more due to stress than read vowels. Shifts for the tense vowels /i/ and /e/ are large, and the directions of the arrows are different for the different speech styles. These details may be artifacts of the small number of tokens and should be studied with more data in the future.

Figure 3.19 shows the same means as Figure 3.18, but arrows point from the means of the read tokens to the means of the spontaneous tokens for each level of stress. Therefore, the length of the arrow in this new figure indicates the magnitude of the effect of style on the vowel midpoints for each level of stress. Secondary-stressed vowels tend to shift more due to style than primary-stressed vowels.

Next, it is asked whether the F1-F2 midpoints of vowels are affected differently by stress or style depending on their consonantal context. Figure 3.20 shows an arrow for each vowel and context. Arrows point from the mean of the read tokens having that context to the mean of the spontaneous tokens. The set of JS vowels used for this plot was all spontaneous tokens and corresponding tokens from the read story. Figure 3.21 also shows an arrow for each vowel and context. In this figure, the arrow points from the mean of

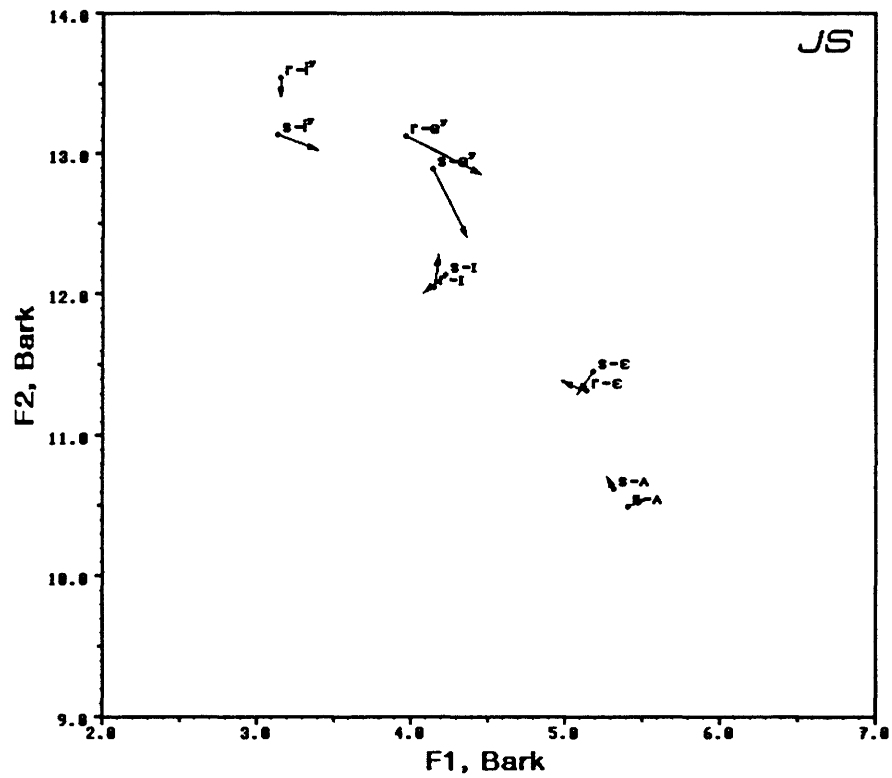


Figure 3.18: Effect of stress on spontaneous vowels compared with effect on vowels from a read story. For each vowel phoneme are shown the F1-F2 means of four groups: the read, primary-stressed vowels; the read, secondary-stressed vowels; the spontaneous, primary-stressed vowels; and the spontaneous, secondary-stressed vowels. Only style is labelled (r=from read story, s=spontaneous). An arrow points from the mean of the primary-stressed group to the mean of the secondary-stressed group for each speech style. Therefore, the length of the arrow indicates the magnitude of the effect of stress on vowel midpoints for each speech style.

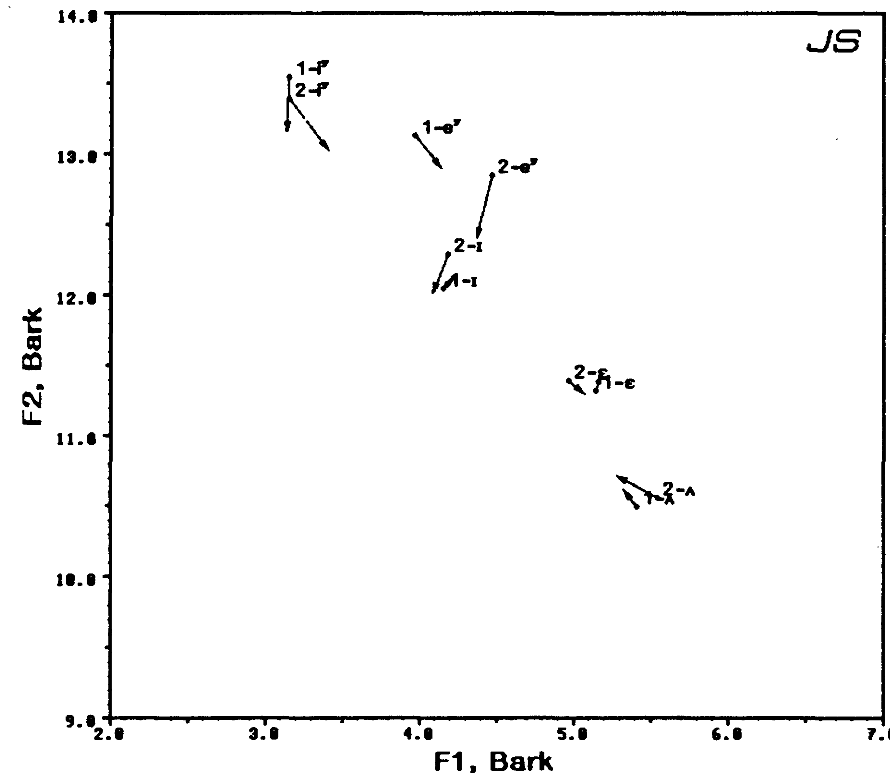


Figure 3.19: Effect of speech style on primary-stressed vowels compared with effect on secondary-stressed vowels. For each vowel phoneme are shown the F1-F2 means of four groups: the read, primary-stressed vowels; the read (from the read story), secondary-stressed vowels; the spontaneous, primary-stressed vowels; and the spontaneous, secondary-stressed vowels. Only stress is labelled (1=primary, 2=secondary). An arrow points from the mean of the read group to the mean of the spontaneous group for each level of stress. Therefore, the length of the arrow indicates the magnitude of the effect of style on vowel midpoints for each level of stress.

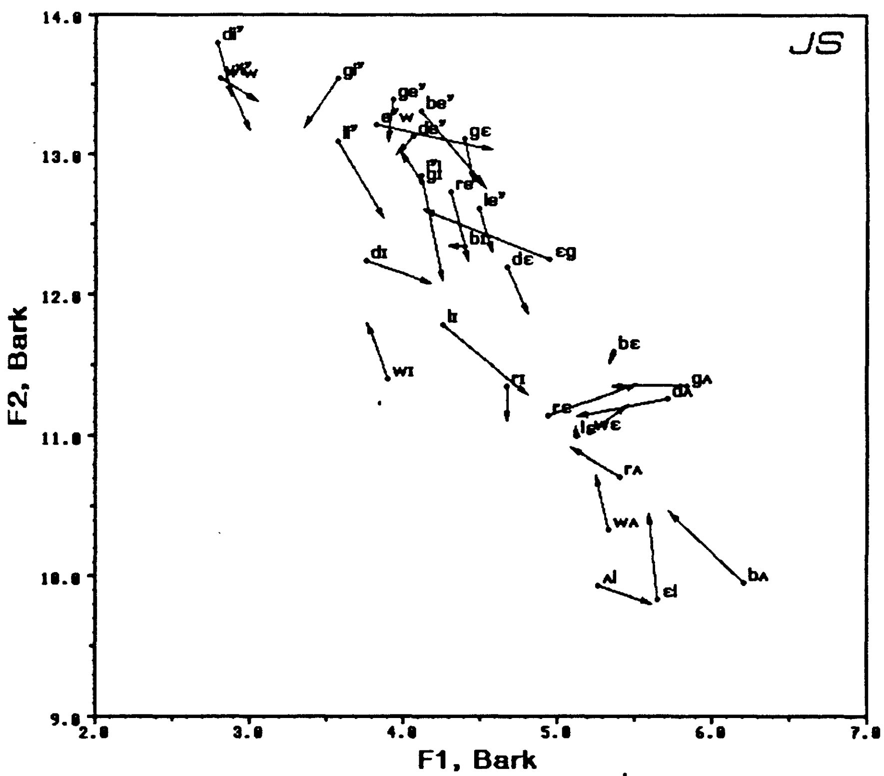


Figure 3.20: Effect of style on F1-F2 midpoints of JS vowels depending on context. Arrows point from the mean of the read tokens having context as labelled to the mean of the spontaneous tokens. The set of JS vowels used for this plot was all spontaneous tokens and corresponding tokens from the read story.

the primary-stressed tokens to the mean of the secondary-stressed tokens. The set of vowels used for this plot was the same as used in the context plot of the previous section, Figure 3.8.

From Figures 3.20 and 3.21, it is clear that the vowels are shifted in different directions depending on their context. The magnitude of the shifts, indicated by the length of the arrows, is greater for the means of the individual contexts than for the overall means seen in Figures 3.9 and 3.11 in the previous section. The directions of the shifts has no obvious pattern, rather, the shifts tend to cancel each other, leading to overall means which do not shift much due to stress or style.

The directions of individual arrows in Figure 3.21 may arise from details of the contexts

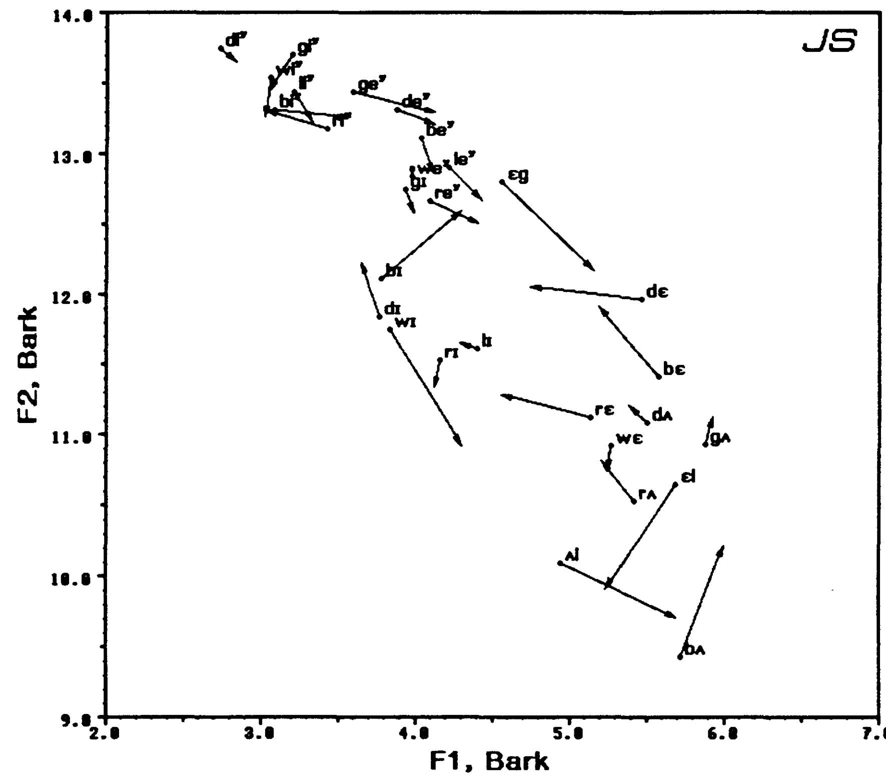


Figure 3.21: Effect of stress on F1-F2 midpoints of JS vowels depending on context. Arrows point from the mean of the primary-stressed tokens having the context as labelled to the mean of the secondary-stressed tokens.

rather than stress itself. In these plots, each mean is represented by repetitions of one word. (The nonsense words were excluded from the means, because the speaker did not seem to differentiate between primary and secondary stress in the nonsense words.) For example, the primary- and secondary-stressed /**ɛg**/ means are represented by the words "integrity" and "architecture," respectively, where the unvoiced velar in "architecture" was allowed because no other suitable word was found. JS tends to produce the voiced velar (/**g**/) as a front velar glide but the unvoiced velar (/**k**/) as a stop. The articulation of the glide is slower than of the stop, and it constrains the tongue body to be front. Therefore, the mean for the primary-stressed /**ɛ**/ vowels tends to lie closer to the locus for the front velar glide, which has a high F2 and a low F1. The alternative word representing primary-stressed /**ɛg**/, "protection," would result in an arrow pointing in a different direction.[2]

Most of the arrows in Figure 3.20 point in the general direction of the center of the vowel quadrilateral, where the neutral schwa vowel produced by a relaxed vocal tract is assumed to lie. Shifting toward the schwa for the spontaneous style is consistent with the theory that spontaneous speech is more relaxed and therefore results in more centralized vowels. However, there are arrows pointing in the opposing direction, for example, for /**wɪ**/ and /**ɛg**/. In the case of /**ɛg**/, the direction may have been caused by a word effect. As for the previous plot, the word was "integrity," and speaker JS tended to pronounce the /**g**/ as a velar glide, which can be considered a reduced form of /**g**/. If JS's /**g**/ tends to be more glide-like in spontaneous speech than in read speech, the vowel midpoint would shift toward the locus of the front velar glide. The shift for /**wɪ**/ and others which are not in the centralizing direction may be due to emphasis or lengthening of certain words in spontaneous speech. Such actions by the speaker, performed to enhance communication, increase the variability of spontaneous speech and are difficult for the experimenter to control.

In summary, secondary-stressed vowels tend to shift more due to style than primary-stressed vowels. Spontaneous speech does not seem to be more affected by stress than read speech, but the direction of shifts is different. Therefore, there is weak evidence

[2]There was only one read-story token of this word for JS, as well as two carrier-phrase repetitions, whose data are shown in Appendix C. The vowel's average F1-F2 midpoint in Bark is (5.65, 11.97).

for interaction between stress and style. There seems to be a large interaction between context and style. Aspects of the context other than place of articulation, which was the only aspect strictly controlled in this study, seem to affect the way style affects the vowels. Spontaneous speech is affected by additional speaker actions, such as emphasis of words to enhance communication. However, caution must be applied in reaching this conclusion, because the number of tokens was small. No conclusions can be drawn concerning the stress-context interaction, because uncontrolled factors may have caused the shifts seen in the means.

Comparison with Previous Studies

Previous studies have reported greater effects of lexical stress and speech style on formant midpoints than the present study has found. Delattre (1969) studied the effects of stress on vowels. Figure 3.22, after Delattre, shows an F1-F2 Bark space plot of averaged midpoints from stressed and unstressed vowels. Delattre compared stressed vowels to what he considered to be their unstressed counterparts, whereas the present study compares primary-stressed vowels to their secondary-stressed counterparts. Delattre's vowels were taken from repetitions of the word pairs "comp<u>e</u>ting/comp<u>e</u>tition" for /**i**/, "exh<u>i</u>bit/exh<u>i</u>bition" for /**ɪ**/, "dis<u>a</u>ble/dis<u>a</u>bility" for /**e**/, "segm<u>e</u>nting/segm<u>e</u>ntation" for /**ɛ**/, and "in s<u>u</u>bstance/ins<u>u</u>bstantial" for /**ʌ**/. The unstressed vowels differ from their stressed counterparts by as much as 2 Bark in F1 (for /**ʌ**/) or F2 (for /**i**/).

The conflict between the conclusion of Delattre's study and the present study can be trivially resolved by noting that secondary-stressed vowels were considered in the present study while reduced vowels were considered in Delattre's study. However, the choice of levels of stress reflects an assumption about the identity of schwa vowels. In the methodology of the present study, Delattre's unstressed vowels would have been labelled schwas on the basis of the word stress pattern. The schwa would then have been considered to have no correspondence to the stressed vowel, and it would have been meaningless to speak of the schwa's "stressed counterpart." That is, the present study assumes that there is a phonological rule which changes all unstressed vowels to the same phonemic schwa vowel.

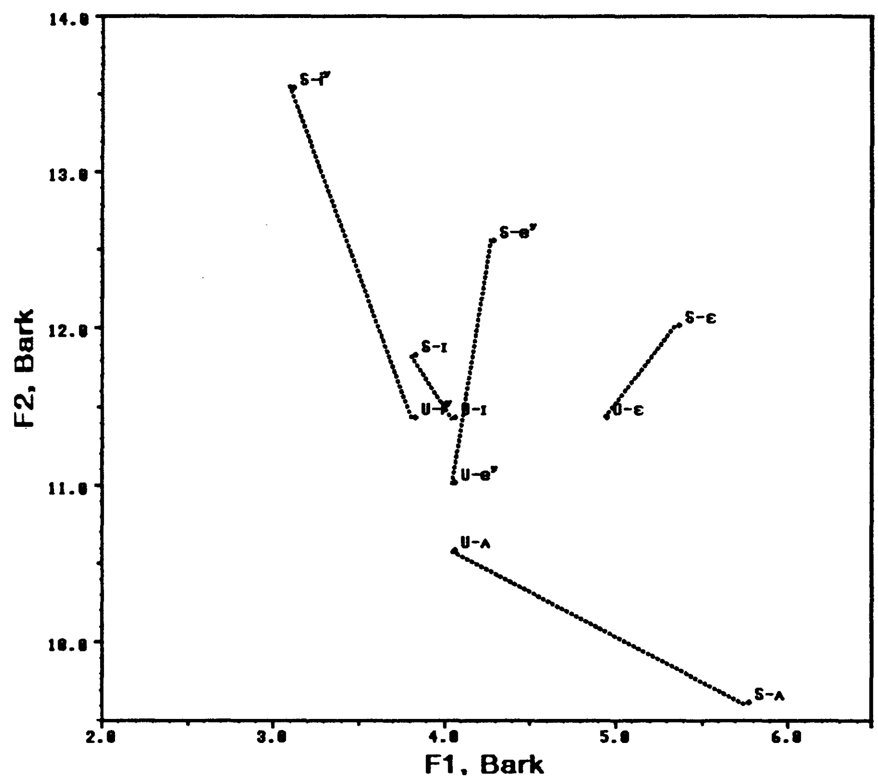


Figure 3.22: F1-F2 plot of averaged midpoints from stressed and unstressed vowels, after Delattre (1969), for comparison with the present study. Delattre's stressed vowels would be called primary-stressed vowels by the criteria of the present study; Delattre's unstressed vowels would be called schwas.

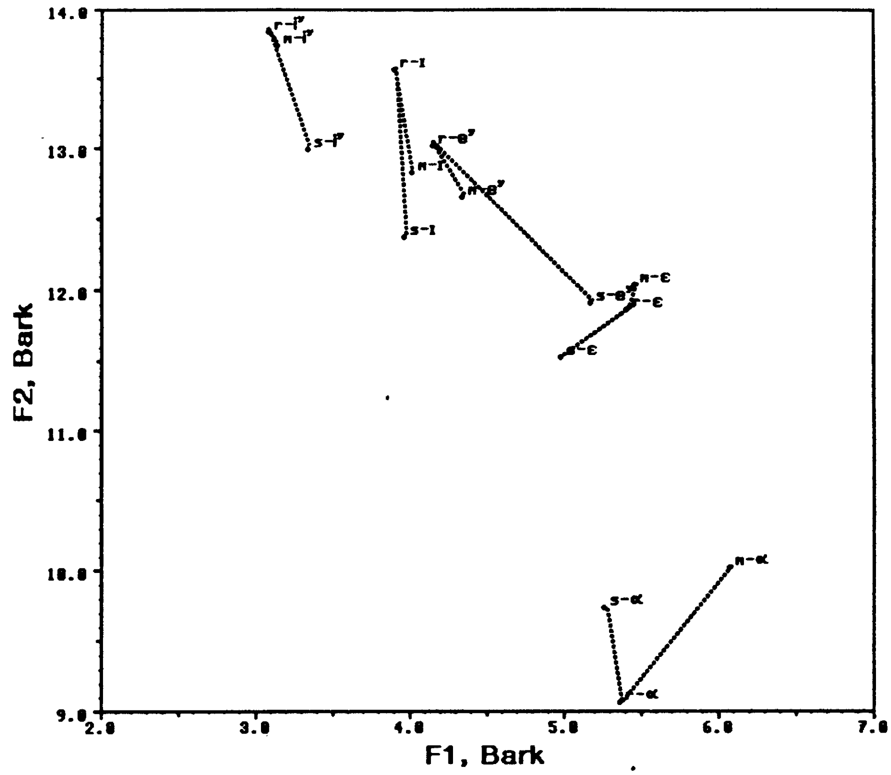


Figure 3.23: F1-F2 plot from Koopmans-van Beinum's study on speech style (1980) for comparison with the present study. Vowels are from isolated monosyllabic words (=m in the labels), read speech (=r), and spontaneous speech (=s). The short Dutch vowel /ɑ/ is comparable to English /ʌ/.

Previous studies of Dutch (Koopmans-van Beinum, 1980), Swedish (Stålhammar et al., 1973), and British English (Swaffield et al., 1961) have shown large effects of speech style on vowel midpoints, whereas previous studies of American English (Shockey, 1973; Ladefoged et al., 1976) and the present study have not. Figure 3.23, from Koopmans-van Beinum's data, shows F1-F2 midpoints of vowels from isolated monosyllabic words, read speech, and spontaneous speech in the form of a retold story. This language dependency may arise from sociolinguistic factors. In some language communities, more of a distinction may be made (in speaker's attitude and practical usage, as well as in the acoustic realization) between formal and informal speech than in other language communities.

Details of the methodology could also have contributed to differences in results. In

Koopmans-van Beinum's study, the read and retold story texts were different, and the consonant contexts of each set of vowels were not controlled. The disparity might have accentuated the differences of the midpoints in the different speech styles, but it is unlikely to have been the main effect since the directions of the shifts are consistent with those of the present study. The methodology of the present study may have lessened the differences between the read and retold (spontaneous) speech. The spontaneous words were elicited shortly after they had been read, and the speakers may have tended to say them more similarly to the read versions than if the words had arisen in an unrelated conversation. Also, speakers may have felt self-conscious repeating a story (and to a certain extent, words) not of their own choosing and therefore may have spoken more formally.

It also must be noted that the choice of speech styles to consider affects the conclusion. Some of the studies mentioned above included isolated vowels, whose formant trajectories and durations tend to be quite different from those of vowels in any style of continuous speech. Isolated vowels were omitted from the present study because they are of limited use in practical applications and because isolated lax vowels cannot be produced naturally in American English.

3.2.2 Effects on Vowel Duration

In spectrograms of the minimum pair in stress shown in Figure 3.15, the formant trajectories of the two vowels are similar. However, the secondary-stressed /ɛ/ is shorter than the primary-stressed /ɛ/. Perhaps there is a more noticeable effect of lexical stress or speech style on vowel duration than on formant frequencies.

Figures 3.24 through 3.26 show the means and standard deviations of the duration distributions of JS vowels categorized by context, stress, and style. The same subsets of data are used as for the F1-F2 plots. An analysis of variance (ANOVA, Johnson and Wichern, 1988; *S+* used to calculate p-values, Becker et al., 1988) was performed on the JS vowels used for each plot as well as for the other three speakers, and the $(1-p)$ values are listed in Table 3.8.

Data from speaker JS will be discussed first. Figure 3.25 shows that, as expected, primary-stressed vowels tend to be longer than secondary-stressed vowels. However, there is no significant difference (if a level of $p \geq .01$ is required) in vowel durations based on primary or secondary lexical stress. The differences based on context and style (nonsense, carrier phrase, or read) are highly significant ($p \geq .001$) for most vowels. There was no significant difference between read and spontaneous duration distributions.

In JS's data, vowels, especially tense vowels, from real words in a carrier phrase tend to be longer whereas those from the read story tend to be shorter. Vowels from the carrier phrase words may be expected to be longer because they are uttered more carefully. However, in the case of /**i**/, prepausal lengthening also plays a part. Although instructed not to by the experimenter, the speaker sometimes paused slightly after the words "fatigue" and "fogeys," resulting in very long /**i**/'s in that context. Vowels from nonsense words are intermediate in duration. Their variances are smaller than those of the other distributions because all factors other than those studied could be held constant.

The significant differences based on context probably arise from a number of factors, including factors which were not controlled, as mentioned in the introduction. Duration differences between vowels adjacent to stop consonants and vowels adjacent to liquids or glides depend directly on how the boundary was set between the vowel and consonant. Several conventions for setting these boundaries can be justified, and therefore durations of vowels in liquid or glide contexts cannot be uniquely determined and will not be considered further in this discussion. Among the vowels in stop contexts, JS's /**bɪ**/ and /**bʌ**/ tokens tend to be longer than the /**dɪ**/ and /**dʌ**/ tokens, which in turn tend to be longer than /**gɪ**/ and /**gʌ**/. In contrast, /**gi**/ tends to be longer than /**di**/ and /**bi**/. Pitrelli (1990) showed that the manner and voicing of the right consonant context has a greater effect on vowel duration than left context place. Therefore, the right consonant voicing and manner, which was not controlled in these tokens, probably accounts for some of the duration differences. Other factors include prepausal lengthening, which sometimes occurred in the carrier phrase or spontaneous conditions, and shortening due to aspiration of the left consonant, which was allowed in a few contexts.

An ANOVA was performed on the vowels in stop contexts from nonsense words only. Values for $(1 - p)$ are listed at the bottom of Table 3.8 for the case where all contexts

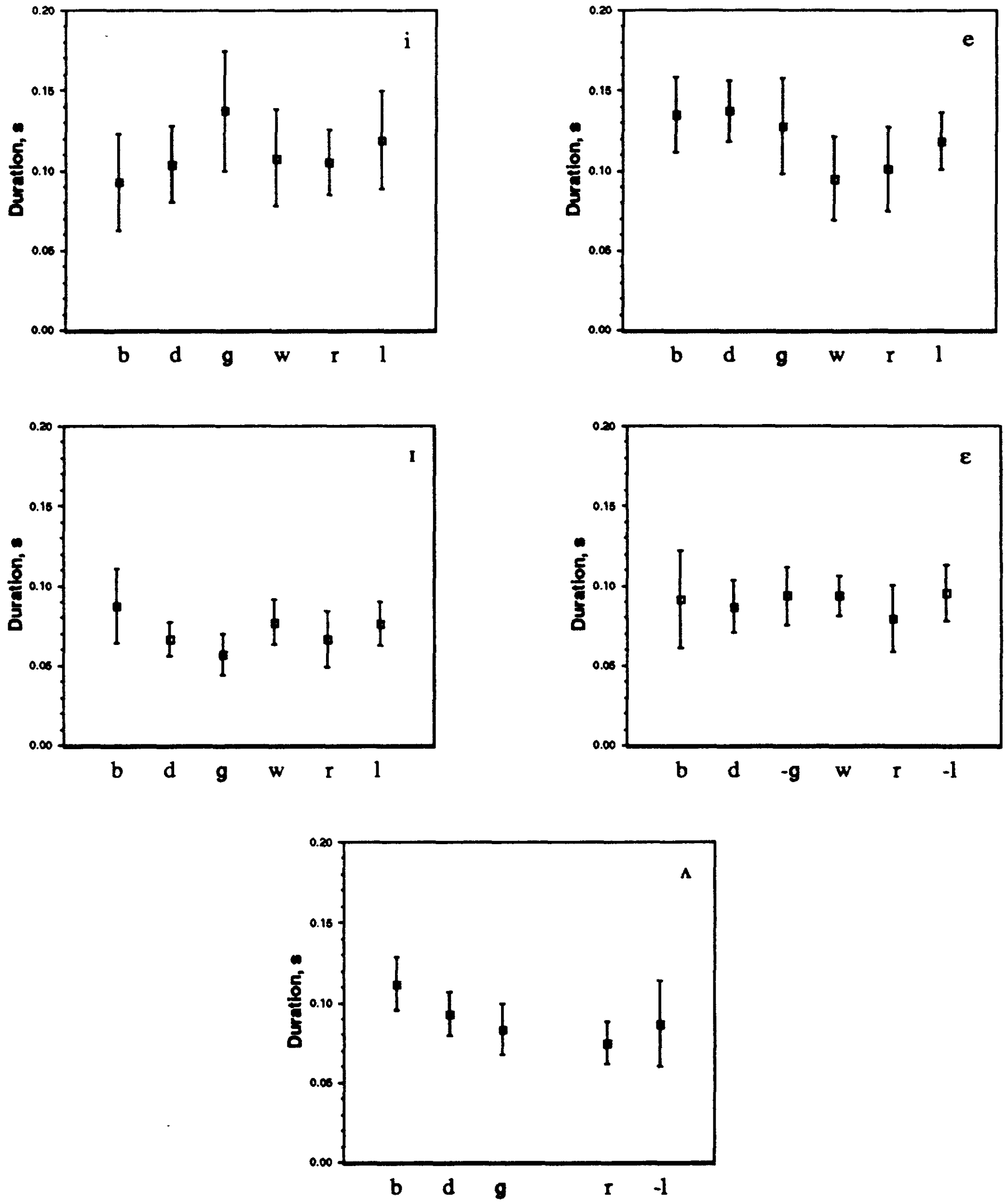


Figure 3.24: Means and standard deviations for durations of JS vowel tokens grouped by consonant context. Consonants refer to initial contexts, except for -g and -l, which are final contexts.

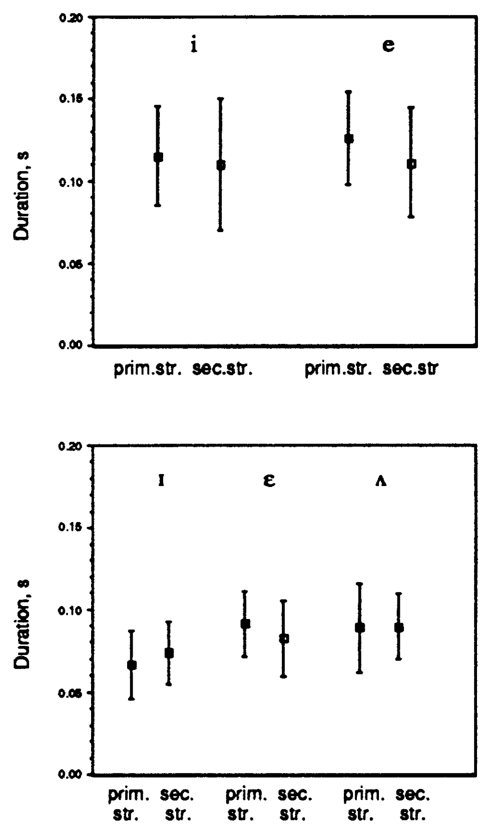


Figure 3.25: Means and standard deviations for durations of JS vowel tokens grouped by lexical stress (primary or secondary).

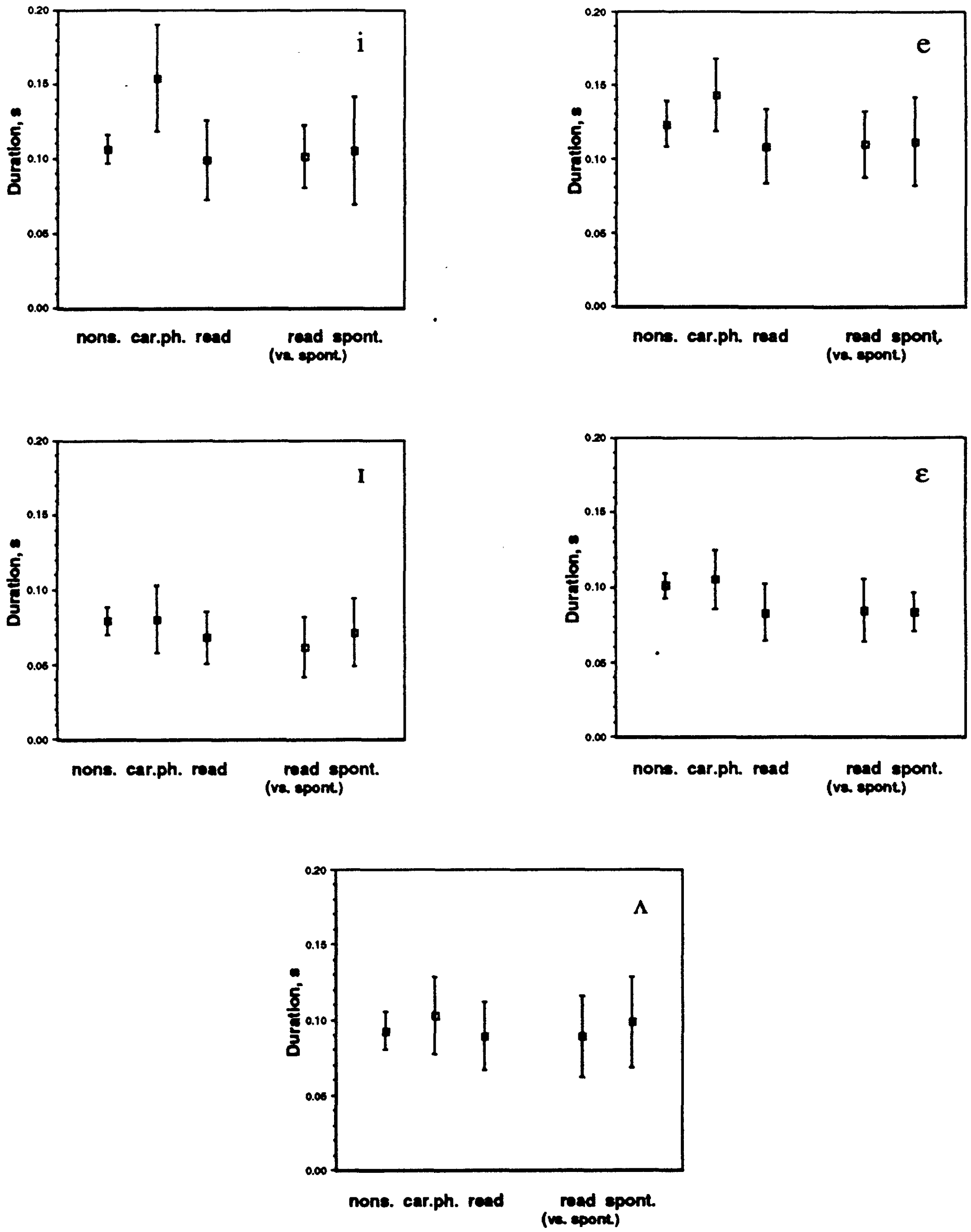


Figure 3.26: Means and standard deviations for durations of JS vowel tokens grouped by speech style (nonsense word, real word in a carrier phrase, read, smaller set of read tokens in which every token corresponds to a spontaneous token, spontaneous.)

are considered and for the stops-only case. There are many fewer tokens (four in each category), but all factors other than the ones studied were controlled. There was no significant difference due to context among the durations within each set of vowels carrying the same phonemic label.

Duration data for the speakers RU, EE, and MP do not show any significant differences due to context, stress, or style within sets of vowels carrying the same phonemic label. For these small sets of tokens, significant differences might have been shown if there had been more tokens. Note for comparison that the differences in formant frequency due to consonant context showed significant differences even with small token sets.

Table 3.8: Values of $(1-p)$ from ANOVA, i.e., probability that the true mean durations of vowels from different context, stress, and style conditions are different. For example, the .957 in the RU, /i/, Context cell means that the probability is .957 that /i/'s in at least one of the contexts (e.g., /**bi**/) have a mean duration which is different from /i/'s in other contexts. ANOVA performed on same set of vowels for context, stress, and style (except for "nonsense only" conditions). Tokens in "style (read/spont.)" set are matched pairs of read and spontaneous versions. Number of tokens (n and n_s) noted for each set.

		n	Context	Stress	Style	n_s	Style(read/spont.)
RU	/i/	24	.957	.561	.277	33	.960
	/ɪ/	24	.999	0.000	.138	36	.730
	/e/	24	.898	.989	.049	51	.831
	/ɛ/	24	.859	.398	.750	39	.913
	/ʌ/	20	.940	.923	.077	30	.365
EE	/i/	24	.998	.557	.077	33	.660
	/ɪ/	24	1.000	.206	.010	42	.646
	/e/	24	.897	.972	.566	54	.619
	/ɛ/	24	.975	.719	.180	42	.990
	/ʌ/	20	.988	.825	.255	27	.565
MP	/i/	24	.990	.257	.574	15	.794
	/ɪ/	24	1.000	.423	.138	30	.657
	/e/	24	.968	.937	.420	45	.856
	/ɛ/	24	.938	.136	0.000	27	.852
	/ʌ/	20	.987	.559	.475	24	.762
JS	/i/	84	1.000	.439	1.000	30	.308
	/ɪ/	84	1.000	.905	.953	22	.704
	/e/	84	1.000	.968	1.000	58	.247
	/ɛ/	84	.893	.938	1.000	42	.158
	/ʌ/	70	1.000	.079	.936	38	.690
JS	/i/	24	.861	-	-	-	-
nons.	/ɪ/	24	.284	-	-	-	-
only	/e/	24	.978	-	-	-	-
	/ɛ/	24	.885	-	-	-	-
	/ʌ/	20	.401	-	-	-	-
JS	/i/	12	.910	-	-	-	-
nons.	/ɪ/	12	.010	-	-	-	-
stops	/e/	12	.324	-	-	-	-
only	/ɛ/	12	.939	-	-	-	-
	/ʌ/	12	.401	-	-	-	-

Comparison with Previous Duration Studies

In the present study, there were significant differences in duration among vowels of the same class spoken in different styles, but no significant difference in their midpoint formant frequencies. This result seems to conflict with the results of Lindblom (1963), who proposed a model in which variations in midpoint formant frequencies could be explained by the vowels' durations alone. However, Lindblom later revised his model to include other factors which affect vowel formants, conceding that the relationship between duration and formant frequency is much less direct. More recently, Van Son and Pols (1989) reported a pilot study with one trained speaker reading the same text at different rates. They found that the speaker's normalized formant trajectories varied very little under the different rate conditions. Their result is in agreement with the present study, in that duration differences were found where formant frequency differences were not. Their trained speaker was apparently able to use auditory feedback to be sure that his articulation reached the same target for a range of speech rates.

The small difference between the stress conditions is in conflict with findings by Crystal and House (1988). Crystal and House found an average difference of 22.6 ms (127.3 ms and 94.7 ms for primary and secondary, respectively, from their Table II) between their stress conditions for all long and short vowels, whereas there is an average difference of 4.3 ms (97.8 ms and 93.5 ms for primary and secondary, respectively) in the present study. The standard deviations of the distributions are comparable in the two studies. The present study may not have shown as large a difference as Crystal and House because it omitted the tense mid and low vowels **/o/**, **/æ/** and **/a/**, whose durations may be most affected by stress conditions. Also, Crystal and House's vowel database may not have been balanced with respect to stress and vowel class. Inherently long vowels may have been more highly represented among the primary-stressed vowels than among the secondary-stressed vowels.

3.3 Characterizing the Formant Trajectory: Using Different Representations of the Vowel as Input to a Gaussian Classifier

As discussed in the introduction, perceptual tests from previous studies have shown that the midpoint of a vowel is an incomplete characterization of the vowel. In this section, aspects of the formant trajectory will be examined. The measure for how well the vowel is characterized will be the percent correct which a Gaussian classifier (Duda and Hart, 1973)[3] achieves using these aspects of the trajectory as input. The maximum likelihood estimator of the covariance is used, and the *a priori* probability of each vowel class is taken into account. For some tokens, the value of a formant needed by a classifier could not be measured because no energy prominence could be seen on a spectrogram or in a spectral slice. (These points were marked 0.0 in the table of data in Appendix C). These tokens were thrown out of the vowel set used for that classifier. Vowels from each speaker were always classified by a model trained on his or her speech only. In all cases, the performance was evaluated by the process of jackknifing, i.e., each token was taken out of the data set in turn and classified by the model trained without that token. To check whether there was enough training data, the jackknifing performance was compared to the performance obtained by testing on training data (i.e., tokens were not taken out). A large disparity between the two performance scores would indicate that there is not enough training data. As the amount of training data increases, the performance score on training data should fall while the score on new data (which the jackknifing procedure approximates) should rise, both performance scores approaching the same limit. For the present database, the jackknifing performance was never more than 3.5% worse than the performance from testing on training data.

The percent correct for the Gaussian classifiers trained on the vowel's durational mid-

[3]For the Gaussian classifier, the vowels are represented by a vector of numbers (e.g., F1 midpoint, F2 midpoint, duration) which associate the vowel with a point in n-dimensional space. In the training phase, estimates of the means and covariance matrices are derived for each vowel class. The multidimensional Gaussian (also called "normal") probability density function is computed from the means and covariances. In the testing phase, the value of the probability density functions for each of the vowel classes is found at the point associated with the vowel token to be identified. The vowel class with the greatest probability is chosen as the vowel identity.

Table 3.9: Percent correct for alternative "midpoints" by Gaussian classifier (jackknifing) for speakers JS, RU, EE, and MP, speaker-dependent. The classifier was trained and tested on (in order of rows) the original durational midpoints of F1, F2, and F3 , the frequencies at the F1 maximum, the extrema of a fitted parabola, the average of F1 and the extrema for F2 and F3, three points from the trajectory, three points and duration, and conditions where the consonant (liquid/glide or stop) context was separated. McNemar's test was performed on scores within each speaker in selected pairs of categories. The level of significant difference was taken to be 0.05. * marks those F1 max., extrema, or F1 ave. scores which were significantly different from the midpoint score. † marks 3 pts. scores which were significantly different from the F1 ave. score. ‡ marks Cont.Sep. 3pt. scores which were significantly different the from 3pt. score. than 2%.

	JS	RU	EE	MP
midpt. (no parab.)	74.1	78.1	69.1	68.7
F1 max. (parab.)	71.0*	74.3	68.2	65.4
extrema (parab.)	75.3	81.5	70.5	66.7
F1 ave. (parab.)	76.3*	82.8*	67.8	67.9
3 pts. (no parab.)	80.9†	83.7	82.6†	80.7†
3 pts. w/ du.	83.5	88.0	87.3	81.6
Cont.Sep. midpt.	80.4	88.8	76.6	81.1
Cont.Sep. 3 pts.	88.2‡	97.5‡	90.7‡	94.0‡
Cont.Sep. 3 pts. w/ du.	91.4	98.3	93.3	97.2

points (F1, F2, F3) according to the original labelling for each speaker is shown in the first row of Table 3.9. The scores range from 69% to 78% correct. RU's vowels are best identified, as may be expected since her midpoint distributions in the F1-F2 plots (Figure 3.1) showed the least overlap among vowel classes of the four speakers.

3.3.1 Alternative One-Point Representations

First, alternative points on the trajectory were explored which might be expected to be better one-point representations of a formant than the durational midpoint, according to assumptions about the production and perception of speech. To smooth the formant trajectories, parabolas were fit to the middle 50% of F1, F2, and F3 for each vowel. Three different strategies were employed to choose the one point from each parabola. The first strategy was to find the maximum of F1 and take the value of F1, F2, and F3 at that time. This might be expected to be the most perceptually salient point because the maximum amplitude of the vowel should coincide with the point where F1 reaches its maximum frequency, according to the acoustic theory of speech production. The second strategy was to find the extremum of the parabola fit to each of the formants, even if the extrema occurred at different points in time. This strategy would be motivated by the theory that articulators aim for a vowel target but do not reach it because of constraints imposed by producing the adjacent consonants. The closest approximation to the target would then be the extrema of the formants in the vowel.[4] The third strategy, suggested by evidence for perceptual averaging of F1 from previous studies (Huang, 1985; Di Benedetto, 1987), was to take an average over the middle 50% of F1 as the F1 value and the extrema for F2 and F3. In cases where an extremum (required to be a maximum in F1 for the first strategy) did not occur within the vowel boundaries, the midpoint was taken. The performance of the Gaussian classifier when given each of these sets of points for each of the speakers is shown in Table 3.9.

The F1 maximum strategy does worse than representing vowels by midpoints for all speakers. The difference is significant to a level of 0.05 by a two-tailed McNemar's test for JS. Comparison of F1-F2 plots based on midpoints and plots (not shown) based on points at F1 maxima shows that the variance of F2 at F1 maxima is greater than at midpoints. The extremum strategy results in a small improvement in performance for RU, but the improvement is not statistically significant. The F1 averaging strategy resulted in statistically significant improvements for JS and RU. However, none of the three alternative one-point representations improved classifier performance markedly.

The next strategy was to represent each formant by three points: the midpoint, the quarter point and the three-quarter point. Performance of the Gaussian classifier with the three points each for F1, F2, and F3 (a nine-point vector) is shown in the middle section of Table 3.9. An improvement of 9% to 14%, depending on the speaker, is achieved over performance given the midpoint alone. This amount of improvement from classifying on the basis of one point per vowel to three points per vowel is similar to that found in previous studies (e.g., Leung's neural net vowel classifier, Leung, 1989). The performance is significantly better than the best one-point representation, F1-ave., for

[4]It is assumed that the closest approximation to the F1, F2, and F3 targets can be reached at different points in time. For F1 and F2, this is equivalent to assuming that the tongue can approximate the target height and backness at different points in time.

Table 3.10: Confusion matrix for the Gaussian classifier trained and tested on JS F1, F2, and F3 midpoints.

	Responses					
Stimuli	i	ɪ	e	ɛ	ʌ	
i	147	6	17	0	0	86%
ɪ	10	107	38	11	1	64%
e	14	5	189	12	0	86%
ɛ	0	12	22	85	43	52%
ʌ	0	7	0	23	105	78%
	86%	78%	71%	65%	70%	Overall: 74.1%

Table 3.11: Confusion matrix for the Gaussian classifier trained and tested on JS F1, F2, and F3, with three points from each trajectory (a nine-point vector).

	Responses					
Stimuli	i	ɪ	e	ɛ	ʌ	
i	144	6	18	0	0	86%
ɪ	5	136	13	10	3	81%
e	10	5	196	9	0	89%
ɛ	0	6	15	103	36	64%
ʌ	0	6	0	20	108	81%
	91%	86%	81%	73%	73%	Overall: 80.9%

three of the four speakers. An additional 1% to 4% improvement is obtained if duration is also given as input. Additional aspects of the trajectory, even represented simply by two additional points and duration, clearly improve the characterization of the vowel. The confusion matrices for the two classifiers on JS data, shown in Tables 3.10 and 3.11, shows that the most improvement between the midpoint and three-point classifiers is in the /ɪ/-/e/ confusion. The fact that a tense-lax confusion is partially resolved suggests that some aspects of the formant trajectory shape are captured by the additional points. The question of how the additional information may be helping is investigated further in the following.

3.3.2 Overshoot and Undershoot

As was discussed earlier, perceptual tests suggest that F1 may be perceived as the time-average of its frequencies, whereas F2 seems to be perceived with an overshoot. A frequency dependency may underlie the apparent difference in perceptual strategies for F1 and F2. Processing the formant trajectories in this way may also lead to improved vowel identification by objective methods (in this case, a Gaussian classifier using a three-point representation of each formant). Performance by the Gaussian classifier was tested for many combinations of amounts of undershoot (an approximation to averaging) and overshoot of F1 and F2.

A simple method of producing an overshoot or undershoot of the trajectory was used. A schematic diagram of the procedure is shown in Figure 3.27. For each formant, the Bark frequency difference between the midpoint and the quarter-point, $d1$, and the midpoint and the three-quarter-point, $d2$, were averaged. The average distance was multiplied by a variable factor, k. The resulting number was added to the midpoint frequency to give the new frequency representing the formant. If the factor k was positive, the effect of perceptual overshoot was simulated; if k was negative, the effect of perceptual undershoot was simulated. However, for simplicity, the factor will be referred to as the "extrapolation factor."

Many combinations of different factors for F1 and F2 were applied to the JS data, and the modified midpoints were used to train and test a Gaussian classifier. The unmodified F3 was also used in the classifier. In Figure 3.28, a surface plot of overall percentage correct is shown as a function of the F1 and F2 factors. The best performance for JS, 77.5%, is obtained with a factor of -1.0 for F1 and 3.0 for F2. That is, the best performance for the Gaussian classifier trained and tested on modified midpoints is obtained with a slight undershoot in F1 and overshoot in F2. For JS, the average overshoot in F2 was 1.5 Bark, and the average undershoot in F1 was 0.3 Bark.

Table 3.12 shows results from the F1-F2 extrapolation experiment for all four speakers. Results for the other three speakers were similar to the results for JS. The scores were a result of testing on training data. The performance of each combination of extrapolation factors was found by jackknifing, but once the best extrapolation factors were found, they

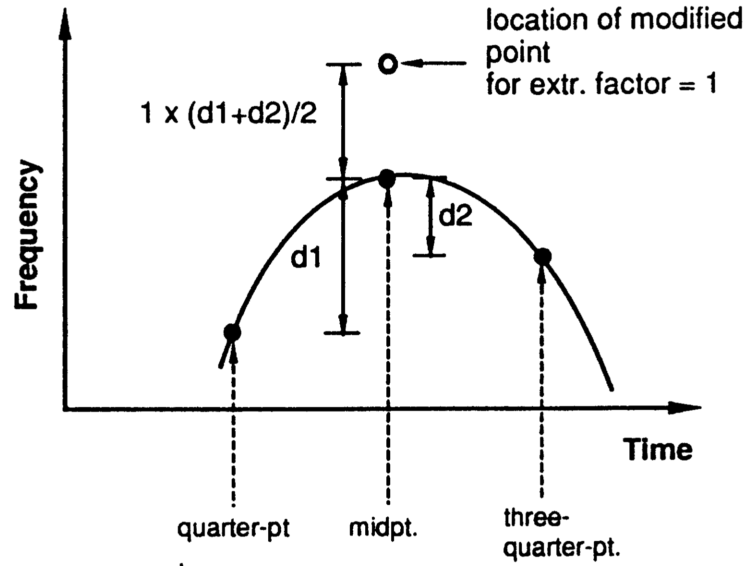


Figure 3.27: Schematized representation of extrapolation procedure. For each formant, the Bark frequency difference between the midpoint and the quarter-point, $d1$, and the midpoint and the three-quarter-point, $d2$, were averaged. The average distance was multiplied by a variable factor, k. The resulting number was added to the midpoint frequency to give the new frequency representing the formant.

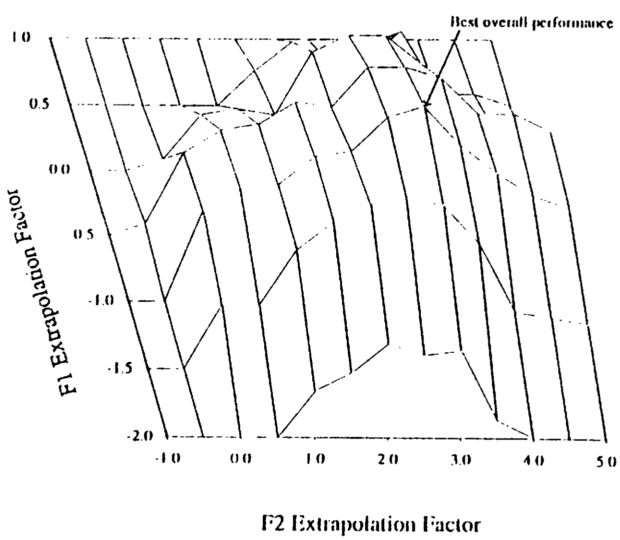


Figure 3.28: Surface plot of percent correct for various values of extrapolation factors for F1 and F2. F1, F2 midpoints from JS data modified by extrapolation procedure and given as input to the Gaussian classifier. Unmodified F3 also provided. Percentages below 74.1%, the performance for *no* modification, set to 74.1.

were not tested on new data. Therefore, the scores may be somewhat inflated and should be interpreted with caution. A more reliable result may be the trend in the sign of the extrapolation factors across speakers. For three of the four speakers, the best performance resulted from a slight undershoot or no change in F1 and overshoot in F2. The vowels whose identification improved the most was included /ʌ/ for all speakers. For all but one speaker, however, the best performance of the classifier using midpoints modified by extrapolation was not as good as the performance when given the three points and duration, as seen by comparing with Table 3.9. The improvement in vowel classification due to information from the formant trajectory has apparently been partially but not fully explained by the extrapolation procedure.

3.3.3 Providing Consonant Context Information

Further improvement in performance by the Gaussian classifier is obtained if consonant context information is provided, as shown in the last rows of Table 3.9. Each score is derived by training and testing two classifiers: one on vowels adjacent to /**w**/, /**r**/, or /**l**/, and one on vowels adjacent to /**b**/, /**d**/, or /**g**/. The combined percentage correct for both types of vowels is reported. Consonant context might be expected to affect vowel identification, since it was shown earlier that context has a great effect on formant midpoints. The improvement in performance when the context is specified explicitly suggests that the context information cannot be derived from the vowel trajectory itself. However, this conclusion may be premature because only very simple representations of the formants were tested.

In summary, none of the one-point representations results in performance of the statistical classifier which is better than providing the classifier with three points from the raw data. There is some evidence simulating a perceptual undershoot in F1 and overshoot in F2 results in better separation of the vowel distributions. A one-point representation which is equivalent to the three points may exist but not be among those tested here. Alternatively, it may be impossible to characterize a vowel with one point per formant. Providing information about consonant context explicitly improves the identification performance by the statistical classifier. In the next chapter, agreement between performance by the

Table 3.12: Data from extrapolation experiments for speakers JS, RU, EE, and MP. Listed are performance by Gaussian classifier given the midpoints, best performance with extrapolation, extrapolation factors which result in best performance (RU had a range of factors, MP had two sets of factors resulting in close scores), and vowel class with most improvement after extrapolation. * marks scores which are significantly different to a level of 0.05 by McNemar's test from the midpoint score.

	Midpt.%Corr.	Extr.%Corr.	Extr.Fac.(F1,F2)	Vow.Imp.
JS	74.1	77.5*	-1, 3	ʌ
RU	78.1	84.1*	-1 to -.5, 1 to 2	ɪ, ʌ
EE	69.1	73.3	1, 1.5	ɛ, ʌ
MP	68.7	71.4	0, 3 (-.5, 1)	ʌ

classifier given different representations of the vowel will be compared to performance by human listeners.

Chapter 4

Results from the Perceptual Study

In this chapter, results from the perceptual study will be presented. Two sets of identification tests were run: the single-speaker tests with speaker JS's vowels only as stimuli and the four-speaker tests with all four speakers' vowels (presented separately). The results from the single-speaker tests were examined most extensively. The four-speaker tests were examined for confirmation only and to note any inter-speaker differences. First, the general pattern of correct and incorrect identifications by listeners will be discussed. Then, the incorrect identifications will be examined more closely. Finally, the models of vowel identification by Gaussian classifiers described in the previous chapter will be compared to the performance by human listeners.

4.1 Pattern of Correct and Incorrect Identifications

4.1.1 Single-Speaker (JS) Data

The results of the identification tests on JS's data were combined for the five listeners and presented in Tables 4.1 and 4.2 as confusion matrices. One of the listeners gave the "other" response in highly ambiguous cases in spite of instructions to make the forced choice. Table 4.1 shows the "no context" condition, and Table 4.2 shows the CVC condition. The "no context" condition, in which only the portion of the speech signal between the vowel boundaries was presented, was intended to be a presentation of the vowel without context. However, influences of the consonants adjacent to the vowel

Table 4.1: Confusion matrix for "No Context" condition from single-speaker (JS) identification tests. One listener gave the "other" response in spite of instructions. "Other" responses were counted as errors in the overall score. * marks confusions in more than one distinctive feature.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	762	51	11	3*	9*	14	90% of 850
ɪ	23	692	11*	47	52*	10	83% of 835
e	65	192*	726	101	2*	14	66% of 1100
ɛ	2*	50	63	494	192	9	61% of 810
ʌ	0*	6*	6*	139	508	16	75% of 675
	89%	70%	89%	63%	67%	0%	Overall: 74.5%

extend into the region within the vowel boundaries, so the vowels were not truly without context. In the single-speaker (JS) tests, listeners were asked to transcribe the syllable they heard, including consonants. In most cases, listeners could correctly identify at least the place of the consonant.

The following general characteristics can be noted from the confusion matrices. In both the "no context" and the CVC conditions, /ɛ/ and /ʌ/ were often confused with each other. Another common error was /e/ called /ɪ/ or /ɛ/ (i.e., tokens which were hand-labelled as /e/'s being identified as /ɪ/ or /ɛ/ by listeners). The most accurately identified vowel was /i/.[1] The overall percent correct was 74.5% in the "no context" condition and 81.9% in the CVC condition. All confusions were less frequent in the CVC condition than in the "no context" condition, except for the /ɪ/ called /i/ and /ɪ/ called /ɛ/ confusions. Other than the case of these two confusions, which were due to errors on vowels from particular words, there is no notable difference in the pattern of errors in the two conditions.[2]

Most confusions involved a false identification of only one vowel feature. For example,

[1]In this discussion, a response will be called "accurate" or "correct" if the listener agreed with the experimenter's transcription. The experimenter's transcription was based on the dictionary pronunciation, as described in the introduction, regardless of the acoustics or perception of the token.

[2]The /ɪ/ called /i/ error arises from /ɪg/ syllables such as in the word "signature," in which JS tends to produce the /g/ as a velar glide. The velar glide is easily mistaken for a /y/-offglide. The /ɪ/-/ɛ/ confusion arises from errors in identifying the first vowels in "schizoid" and "schizophrenic."

Table 4.2: Confusion matrix for CVC condition from single-speaker (JS) identification tests. Fewer errors than in "No Context" condition but pattern of errors similar. One listener gave the "other" response in spite of instructions. "Other" responses were counted as errors in the overall score. * marks confusions in more than one distinctive feature.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	818	12	5	0*	3*	12	96% of 850
ɪ	30	685	3*	58	51*	8	82% of 835
e	59	136*	817	74	1*	13	74% of 1100
ɛ	1*	28	30	604	127	20	75% of 810
ʌ	1*	2*	3*	77	572	20	85% of 675
	90%	79%	95%	74%	76%	0%	Overall: 81.9%

the /e/ called /ɪ/ error is a misidentification of tenseness only, and the /ɛ/ called /ʌ/ error is a misidentification of backness only. In the "no context" condition, only 8.1% of the total number of responses were errors in two or more features, counting the "other" responses as such errors. In the CVC condition, 6.4% of the responses were errors in two or more features. That is, if errors in one feature were allowed, the percent "correct" would be 91.9% and 93.6% in the "no context" and CVC conditions, respectively.

Percent information transmitted, a measure based on the notion of mutual information from information theory, was calculated to quantify how well the vowel features high/non-high, front/back, and tense/lax were identified. Data from the CVC condition were used. (Data from the "no context" condition would be expected to yield similar results because the pattern of errors is similar.) The *percent information transmitted*, described by Wang and Bilger (1973), takes into account the differing proportional representation of each of the features in the database and prevents misleading high scores in the case of uneven representation. For example, since /ʌ/ was the only back vowel in the database, only 16% of the vowels in the database had the feature [+back]. If identification accuracy of backness were measured by a simple percent correct, a high score (84%) would result if the listeners were to always respond "[-back]" (equivalently, "[+front]"). By the percent information transmitted measure, the score would be 0, because the performance was no better than if the listeners had been told the proportion of back vowels in the database but had not heard any stimuli.

The *percent information transmitted* was 64.1%, 58.8%, and 56.4% for the features tense/lax, high/non-high, and front/back, respectively. That is, tenseness was most accurately identified by listeners and frontness was least accurately identified (but the measure was not very different for frontness and height). Since the vowel and consonant context sets are not distributionally representative of running speech, no conclusions can be drawn about the transmission of feature information in speech in general. The relatively poor identification of front/back may be the perceptual result of F2 being lower in frequency for many vowel tokens in the stimulus set than is typical for canonical versions of those vowels. The /w/, /r/, and /l/ contexts, which are heavily represented, tend to lower F2 in front vowels, which are also heavily represented. The relatively good identification of tense/lax is unexpected on the basis of previous perceptual studies using

Table 4.3: Results from single-speaker (JS) identification test. Percent correct for each listener (numbered 1 through 5) for each vowel and overall. "Ave." column shows average of five listeners.

		Listeners					
		1	2	3	4	5	Ave.
"No Context"	/i/	89.	92.	84.	89.	94.	90.
	/ɪ/	89.	76.	77.	86.	87.	83.
	/e/	69.	89.	67.	63.	42.	66.
	/ɛ/	65.	66.	57.	59.	57.	61.
	/ʌ/	68.	77.	70.	85.	76.	75.
	Overall	76.	81.	71.	76.	69.	75.
CVC	/i/	98.	98.	90.	97.	98.	96.
	/ɪ/	89.	72.	75.	83.	91.	82.
	/e/	76.	87.	74.	79.	56.	74.
	/ɛ/	77.	81.	70.	71.	73.	75.
	/ʌ/	87.	79.	83.	91.	84.	85.
	Overall	85.	84.	78.	84.	79.	82.

vowels excised from running speech. In the previous studies, described in the introduction (Koopmans-van Beinum, 1980; Verbrugge, 1976), tense/lax or long/short confusions tended to predominate in the errors because the lack of speaking rate information caused the stimulus to sound artificially short. This study was not as affected by that problem, probably because the tense low vowels /æ/ and /ɑ/, which have been shown to be perceptually distinguished from the lax vowels /ɛ/ and /ʌ/ largely on the basis of duration (see, for example, Huang, 1985), were not included in the vowel set.

The five listeners varied in the percent correct of their responses, as shown in Table 4.3. The overall percent correct ranged from 69% to 81% in the "no context" condition and from 78% to 85% in the CVC condition. The listeners all identified /i/ most accurately in both conditions. They differed most in the identification of /e/, ranging from 42% correct to 89% correct in the "no context" condition. The pattern of errors was still similar between the two listeners who were at the extremes of the range. When /e/ was misidentified, both listeners tended to respond with /ɪ/ and /ɛ/.

Table 4.4: Confusion matrix for "No Context" condition for JS from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	181	20	5	0	9	0	84%
ɪ	3	171	4	14	28	0	78%
e	31	33	205	20	1	0	71%
ɛ	0	13	18	134	60	0	60%
ʌ	0	4	2	44	115	0	70%
	84%	71%	88%	63%	54%	0%	Overall: 72.3%

4.1.2 Four-Speaker Data

The four-speaker tests, which included approximately 200 tokens from JS and each of the three other speakers (presented separately), were run with five listeners, none of whom had participated in the single-speaker (JS) tests. The confusion matrices for each speaker are shown in Tables 4.4 to 4.11. Detailed comparison with the confusion matrices for the single-speaker (JS) tests shows both speaker and listener differences. Surprisingly, the number of /ɪ/ called /ʌ/ confusions, an error of two features (height and backness) is large for all speakers and proportionally greater than the number of such confusions for JS in the single-speaker tests. The high frequency of this confusion can be traced to two of the new listeners. The /e/ called /ʌ/ confusion (an error of two features, tenseness and backness)[3] is common for MP, and the /ʌ/ called /ɛ/ confusion occurs much less often for RU than for the other speakers. Otherwise, the data are similar to the data from the single-speaker (JS) tests.

The overall performance is lower for the four-speaker tests than for the single-speaker (JS) tests. The lower performance could simply be due to the difference in listeners who participated in the two sets of tests, but it could also be due to methodological differences. Vowel identification in the multiple-speaker condition tends to be more difficult than in the single-speaker condition (see, e.g., Strange et al., 1976). Even though the tokens of the four speakers were presented separately, the multiple-speaker effect could have

[3]The /e/ called /ʌ/ confusion arises from MP's utterance of "azalea," in which the /l/ sounds like /ʌ/.

Table 4.5: Confusion matrix for CVC condition for JS from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	203	7	1	0	4	0	94%
ɪ	9	173	0	17	21	0	79%
e	21	54	186	28	1	0	64%
ɛ	0	8	8	147	62	0	65%
ʌ	1	2	0	11	151	0	92%
	87%	71%	95%	72%	63%	0%	Overall: 77.1%

Table 4.6: Confusion matrix for "No Context" condition for RU from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	173	34	16	1	1	0	77%
ɪ	1	185	0	15	39	0	77%
e	2	19	220	59	5	0	72%
ɛ	0	2	9	146	68	0	65%
ʌ	1	12	1	27	129	0	76%
	98%	73%	89%	59%	53%	0%	Overall: 73.2%

Table 4.7: Confusion matrix for CVC condition for RU from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	184	30	11	0	0	0	82%
ɪ	3	203	0	14	20	0	85%
e	0	4	260	40	1	0	85%
ɛ	0	0	2	164	59	0	73%
ʌ	0	13	0	4	153	0	90%
	98%	81%	95%	74%	66%	0%	Overall: 82.7%

Table 4.8: Confusion matrix for "No Context" condition for EE from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	202	18	4	1	0	0	90%
ɪ	4	190	0	17	39	0	76%
e	7	45	219	36	3	0	71%
ɛ	1	25	5	156	43	0	68%
ʌ	1	8	1	76	79	0	48%
	94%	66%	96%	55%	48%	0%	Overall: 71.7%

Table 4.9: Confusion matrix for CVC condition for EE from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	210	10	2	1	2	0	93%
ɪ	2	215	0	14	19	0	86%
e	11	20	237	37	5	0	76%
ɛ	0	11	6	178	35	0	77%
ʌ	2	1	0	38	124	0	75%
	93%	84%	97%	66%	67%	0%	Overall: 81.7%

Table 4.10: Confusion matrix for "No Context" condition for MP from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	150	28	8	1	8	0	77%
ɪ	2	147	10	12	59	0	64%
e	11	53	190	17	24	0	64%
ɛ	2	12	13	106	72	0	52%
ʌ	0	9	0	28	123	0	77%
	91%	59%	86%	65%	43%	0%	Overall: 66.0%

Table 4.11: Confusion matrix for CVC condition for MP from four-speaker identification tests.

	Responses						
Stimuli	i	ɪ	e	ɛ	ʌ	other	
i	167	18	9	0	1	0	86%
ɪ	3	165	2	17	43	0	72%
e	15	29	202	30	19	0	68%
ɛ	1	3	4	151	46	0	74%
ʌ	1	8	0	18	133	0	83%
	89%	74%	93%	70%	55%	0%	Overall: 75.4%

had an influence. Another difference in procedure was that subjects were not required to transcribe the syllable for the four-speaker tests, as they were for the single-speaker tests. Lack the of explicit segmentation required by transcribing may have caused the listeners to hear liquid or glide consonant contexts as part of the vowel. For example, one listener noted that he heard an /ɛl/ sequence to be /ʊ/-like. Also, the time allowed for response between stimuli was shorter for the four-speaker tests than for the single-speaker tests.

4.2 Analysis of Identification Errors on Single-Speaker (JS) Data

In Chapter 3, the acoustic properties of the vowel tokens were described, and the effect of the consonant context, lexical stress, and speech style on the acoustic properties was examined. In the following discussion, the effect of the acoustic properties and of the three factors on the perception of the vowels will be explored. The most common perceptual confusions were /e/ called /ɪ/, /e/ called /ɛ/, /ɛ/ called /ʌ/, and /ʌ/ called /ɛ/. The tokens which were involved in these confusions in the single-speaker (JS) tests were analyzed further.

4.2.1 Acoustics of Correctly and Incorrectly Identified Tokens of /e/, /ɛ/, and /ʌ/

The data presented in Chapter 3 show differences in the location of F1-F2 midpoints, the duration, and the formant trajectories among the vowels /e/, /ɪ/, and /ɛ/. The tense vowel /e/ tends to be longer than either of the lax vowels /ɪ/ or /ɛ/, and the tense vowel tends to have a /y/-offglide whereas the lax vowels do not. F1-F2 midpoint location is the most apparent acoustic difference between /ɛ/ and /ʌ/. Tokens may be expected to be misidentified if their F1-F2 midpoints fall close to the mean F1-F2 midpoints of vowels labelled as different vowel phonemes by the experimenter. Shorter tokens and those without the typical /y/-offglide may be expected to be misidentified as lax vowels. These expectations are confirmed when the acoustic properties of correctly and incorrectly identified tokens are analyzed.

Speaker JS's /e/ tokens were divided into three groups: those identified correctly by listeners (the /e/-called-/e/ group), those identified as /ɪ/ (the /e/-called-/ɪ/ group), and those identified as /ɛ/ (the /e/-called-/ɛ/ group). The /ɛ/ tokens were similarly divided into the /ɛ/-called-/ɛ/ group and the /ɛ/-called-/ʌ/ group. The /ʌ/ tokens were divided into the /ʌ/-called-/ʌ/ group and the /ʌ/-called-/ɛ/ group. Since the results from the "no context" condition and the CVC condition were similar, data from the two conditions were pooled for the figures shown in this chapter. Averages of the acoustic properties were then calculated for each of these groups. For the averages, each stimulus presentation and response was treated as if it were a separate token. The following example illustrates how the averages were taken. Each listener listened to each vowel token once in the "no context" condition and once in the CVC condition. Suppose three listeners identified a particular /e/ token as /ɪ/ and two listeners identified the same token as /e/ in the "no context" condition, and all listeners identified the token as /ɪ/ in the CVC condition. The acoustic data from that /e/ token would included eight times in the averages for the /e/-called-/ɪ/ group and two times for the /e/-called-/e/ group.

Figure 4.1 shows the distributions of F1-F2 midpoints of correctly and incorrectly identified /e/, /ɛ/, and /ʌ/ vowels. The distributions are modelled as two dimensional Gaussians, and the centroids, or means, and the equal probability contour one standard deviation away from the mean are plotted. The /e/-called-/ɪ/ and /e/-called-/ɛ/ centroids are slightly shifted toward the location of JS's /ɪ/ and /ɛ/ vowels (see Figure3.1 in Chapter 3), relative to the correctly identified /e/ tokens. However, the shift is small compared to the standard deviation of the data. There is also a small shift of the /ʌ/-called-/ɛ/ centroid toward the /ɛ/ distribution location. In contrast, the /ɛ/ called /ʌ/ centroid is greatly shifted toward the /ʌ/ location. The /ɛ/ tokens with low F2 frequencies tend to be those with an adjacent liquid or glide (as Figure 3.8 in Chapter 3 shows). The F2 of the front vowel/ɛ/ tends to be greatly lowered, while the F2 of the back vowel /ʌ/ is less affected, presumably because it is close to the F2 locus for /w/, /r/, and /l/. There are more instances of /ɛ/ called /ʌ/ than vice versa, a situation which mirrors the acoustic data, which show that /ʌ/ midpoints do not tend to stray into the area of the /ɛ/'s with higher F2 frequencies. The directions of the shifts of the centroids confirm the expectation that a token will tend to be perceived as the vowel phoneme for which the token's F1-F2 midpoint values are typical. However, the small size of the shifts suggests that a misleading F1-F2 midpoint value is not the only cause of misidentification for /e/ and /ʌ/. For example, the small shift of the /e/-called-/ɪ/ F1-F2 centroid toward the /ɪ/ region could arise from some of the misidentified tokens straying far into /ɪ/ region, while other tokens had F1-F2 midpoint values typical for /e/ but were misidentified due to other factors to be discussed below.

It may be hypothesized that /e/'s which are shorter tend to be misidentified as lax vowels. Figure 4.2 shows means and standard deviations for the durations of /e/, /ɛ/, and /ʌ/ divided into groups of correctly and incorrectly identified tokens. As expected, the /e/ tokens which were correctly identified are longer on average than the /e/ tokens which were misidentified as lax vowels. The differences in the means are on the order of 30 ms, which is the approximate duration of a just-noticeable difference (JND) for segments of 100 ms duration (Pitrelli, 1990, after Lehiste). The difference is smaller than the standard deviation, suggesting that duration is not the only cause of misidentification. For comparison, the data for /ɛ/ and /ʌ/ show no systematic differences in duration between correctly and incorrectly identified tokens.

One aspect of the formant trajectory is described in Figures 4.3 through 4.5. A parabola is fitted to the F1 and F2 trajectories of each token, and the time location of the extreme point (maximum or minimum) is found. The vowel tokens are then categorized according to whether the extremum of each formant occurred before the vowel boundaries, in the first third of the vowel, in the middle third, in the final third, or after the vowel boundaries. If the extremum occurred outside the vowel boundaries, the formant trajectory was monotonically increasing or decreasing. The number of tokens in each category are shown in bar graphs. Figure 4.3 shows that the /e/-called-/e/ group is dominated by tokens whose F2's have an extremum in the last third of the vowel, presumably a maximum due to a /y/-offglide followed by a fall toward the consonant locus at the end of the vowel. A /y/-offglide with no fall toward a consonant locus would result in a monotonically increasing F2, and the extremum of the fitted parabola would probably occur after the vowel boundaries. Tokens of this type constitute the second largest fraction of the /e/-called-/e/ group. A fall toward the consonant context may enhance the cue for the /y/-offglide, though, because it would be unambiguous that the maximum in F2 was

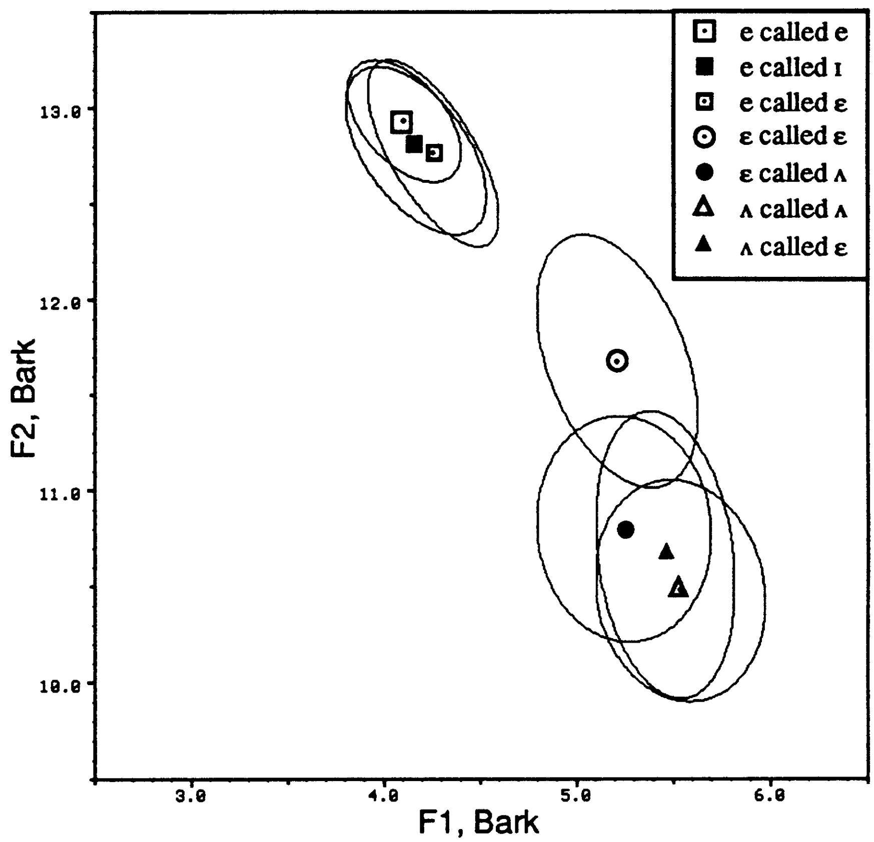


Figure 4.1: F1-F2 midpoint distributions of /e/, /ε/, and /ʌ/ divided into groups of correctly and incorrectly identified tokens from single-speaker (JS) tests. For example, tokens labelled by the experimenter and identified by the listeners as /e/ form the /e/-called-/e/ group. Distributions modelled as two-dimensional Gaussians. Means and equal probability contour one standard deviation away from mean plotted. F1-F2 means for incorrectly identified tokens shift toward the F1-F2 region for the incorrect vowel.

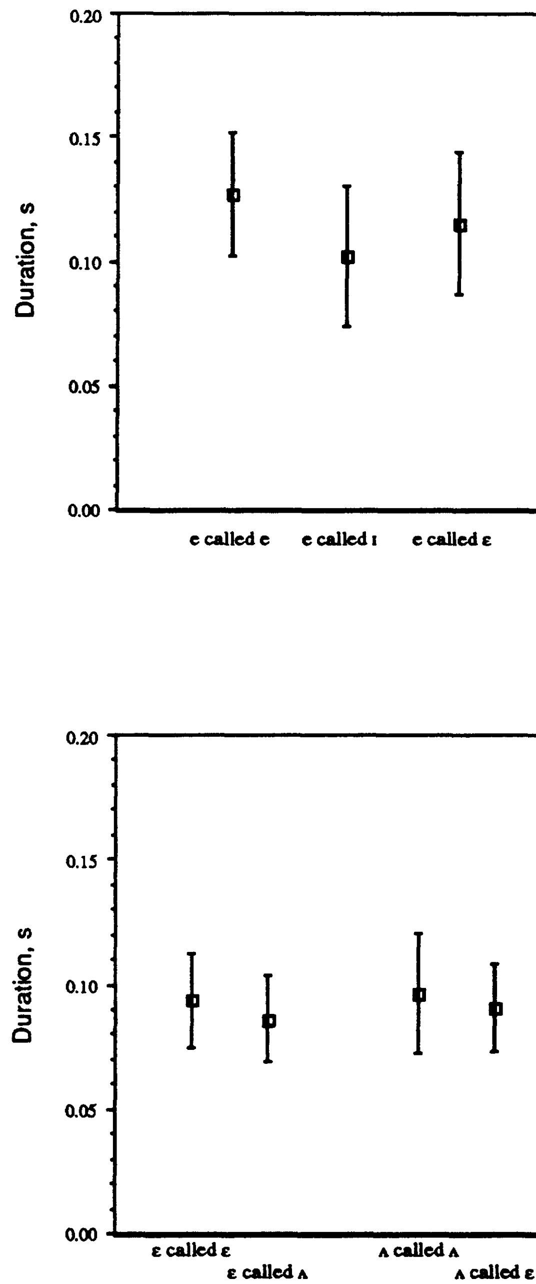


Figure 4.2: Means and standard deviations for durations of /e/, /ε/, and /ʌ/ divided into groups of correctly and incorrectly identified tokens from single-speaker (JS) tests. For example, tokens labelled by the experimenter and identified by the listeners as /e/ form the /e/-called-/e/ group. Correctly identified /e/ tokens are longer on average than /e/ tokens which were misidentified as lax vowels.

due to the offglide and not to a high-frequency consonant locus. In contrast, the sets of /**e**/ tokens which were misidentified as lax vowels were not dominated by tokens whose F2 had a late extremum.

The F1 trajectories of the misidentified /**e**/ tokens are not similar to those of /ɪ/ and /ɛ/ tokens, as can be seen by comparing Figure 4.3 with Figure 3.7 in Chapter 3. The lax vowels in Figure 3.7 tend to have an F1 peak in the middle of the vowel. This F1 characteristic is not highly represented in the /**e**/-called-/ɪ/ and /**e**/-called-/ɛ/ groups, suggesting that the characteristic is not essential for creating the percept of /ɪ/ or /ɛ/.

For comparison, Figures 4.4 and 4.5 shows similar graphs describing the F1 and F2 trajectories of correctly and incorrectly identified /ɛ/ and /ʌ/. No striking differences can be seen between the correctly and incorrectly identified tokens.

4.2.2 Effect of Consonant Context, Lexical Stress, and Speech Style

Figures 4.6 and 4.7 show the representation of different consonant contexts in the groups of correctly and incorrectly identified tokens of /**e**/, /ɛ/, and /ʌ/. The y-axis of the bar graphs is labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered to be a "token," as in the above analysis. Representation of the contexts varies greatly between the groups of correctly and incorrectly identified tokens. Tokens of the vowel /**e**/ in the /**d**/- and /**l**/-initial contexts tend to be correctly identified by listeners, whereas /**e**/ tokens in the /**g**/-initial and /**l**/-final contexts tend to be misidentified. The misidentified tokens are taken mainly from the words "gator," "alligator," "azalea," and the nonsense words "dailacated" and "dailacation." Tokens of /ɛ/ in the /**w**/-initial context tend to be misidentified as /ʌ/, and tokens of /ʌ/ in the /**l**/-final context tend to be misidentified as /ɛ/. The misidentified tokens in these categories are taken mainly from the words "question," "questionnaire," "adulterated," "insult," and the nonsense words "dulacated" and "dulacation."

The confusions can be explained by noting the effects of the consonant contexts on the formant midpoint values and formant trajectory shapes. In some cases, transconsonantal context, a factor which was not controlled in this study, also seems to be affecting the

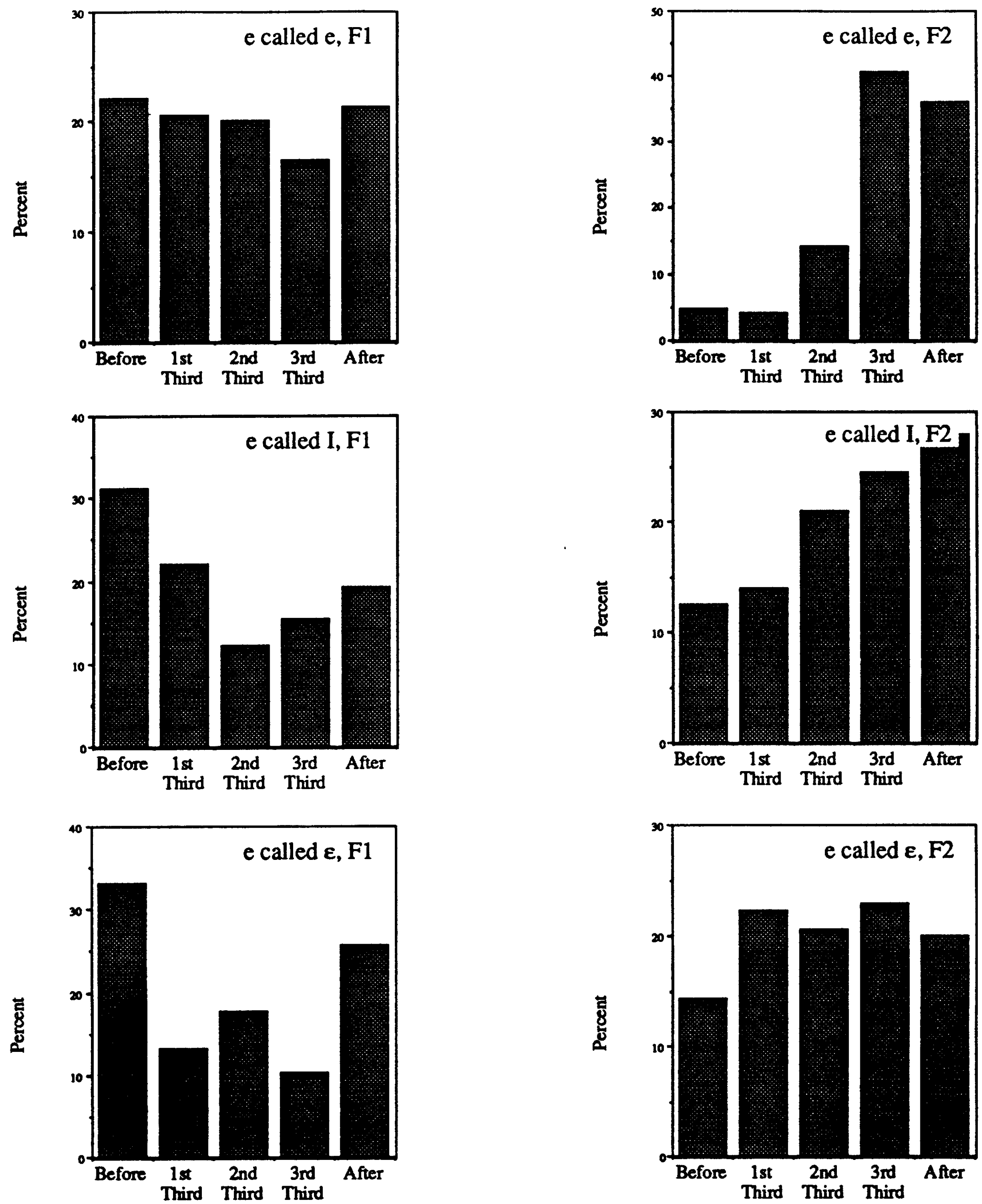


Figure 4.3: /e/ divided into groups of correctly and incorrectly identified tokens from single-speaker (JS) tests, categorized according to location of extremum (maximum or minimum) in F1 and F2 trajectories. Extremum occurs before vowel boundaries, in first, middle, or final third of vowel, or after vowel boundaries. Correctly identified /e/ (/e/-called-/e/ group) tokens tend to have late extremum, due to /y/ offglide.

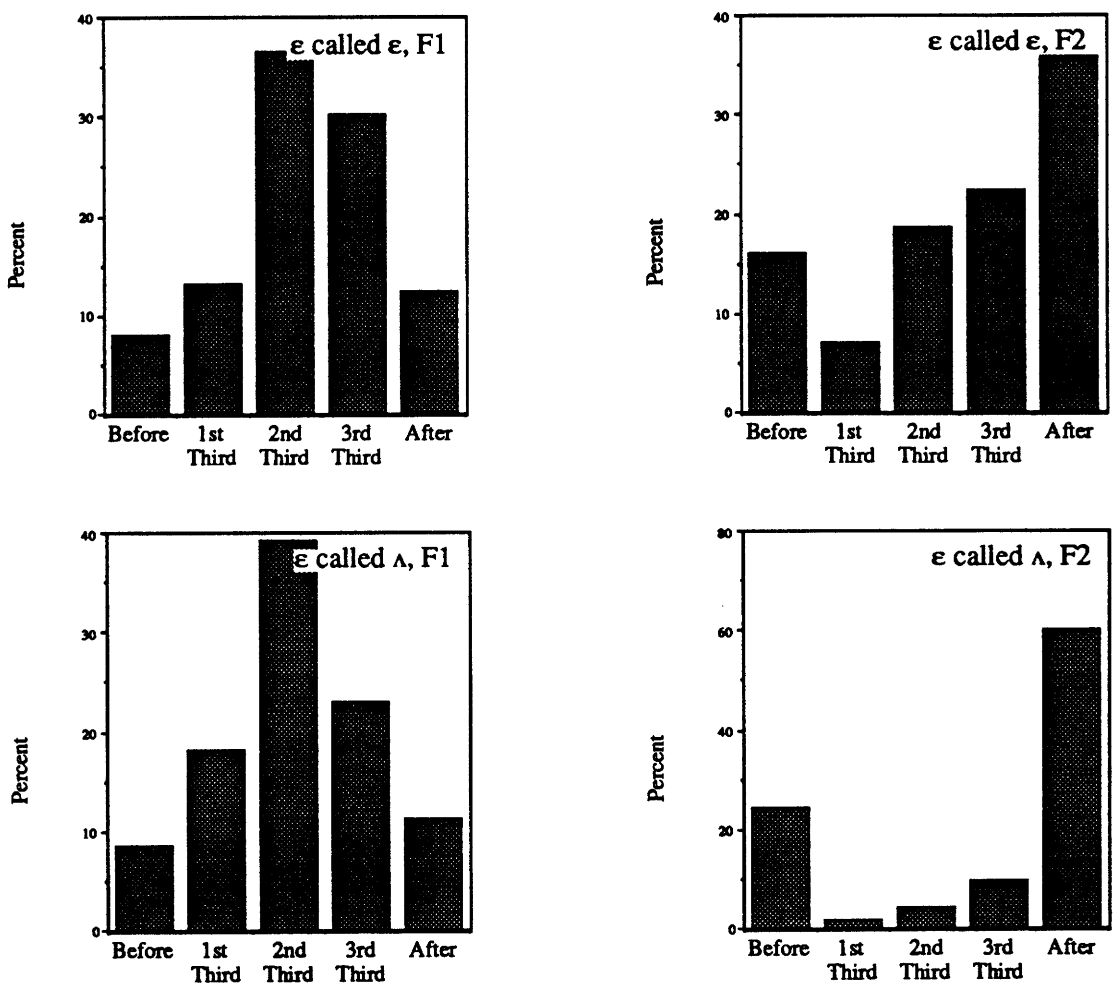


Figure 4.4: Tokens of /ε/ divided into groups of correctly and incorrectly identified tokens from single-speaker (JS) tests, categorized according to location of extremum (maximum or minimum) in F1 and F2 trajectories. Extremum occurs before vowel boundaries, in first, middle, or final third of vowel, or after vowel boundaries. No differences seen in trajectories of correctly and incorrectly identified /ε/.

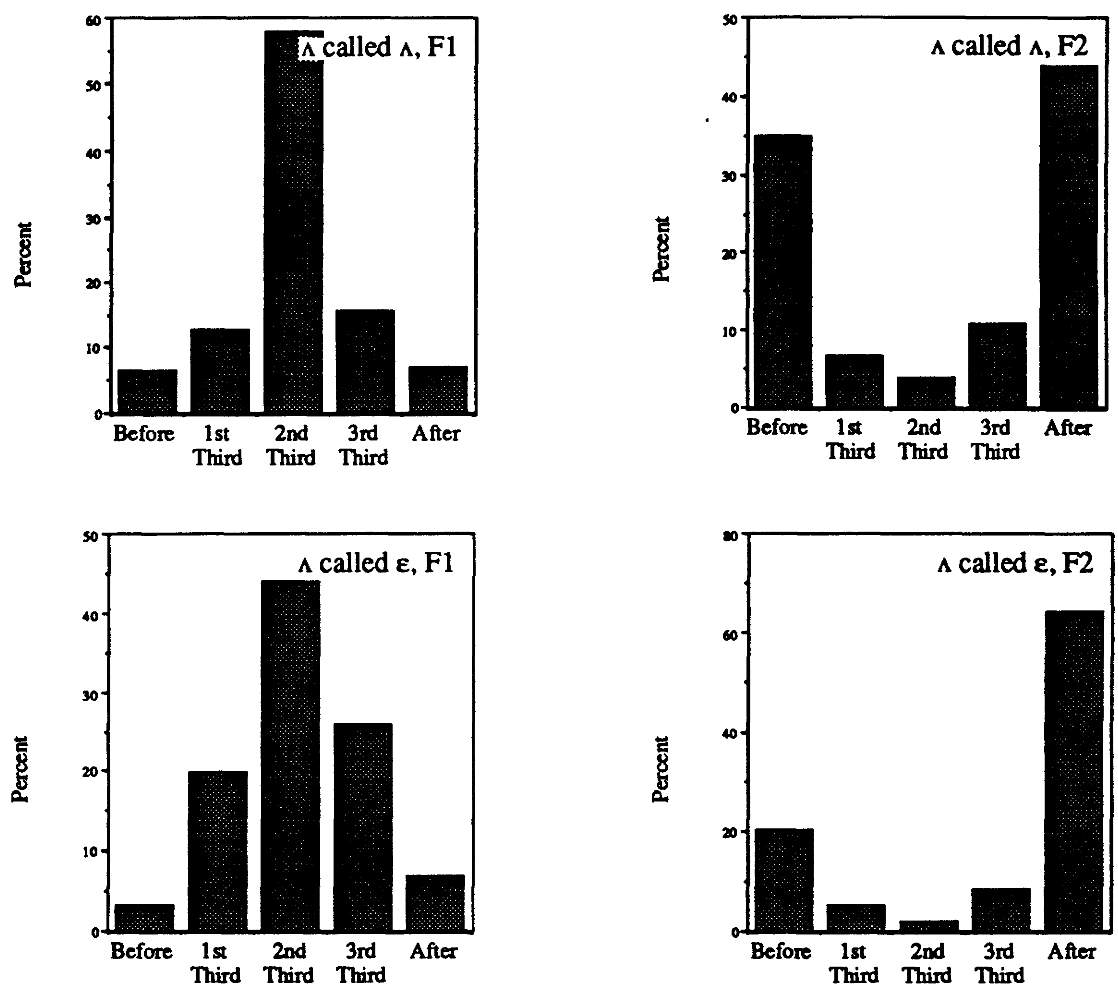


Figure 4.5: Tokens of /ʌ/ divided into groups of correctly and incorrectly identified tokens from single-speaker (JS) tests, categorized according to location of extremum (maximum or minimum) in F1 and F2 trajectories. Extremum occurs before vowel boundaries, in first, middle, or final third of vowel, or after vowel boundaries. No differences seen in trajectories of correctly and incorrectly identified /ʌ/.

identification of the vowel.

The representation of vowels carrying primary and secondary lexical stress in the groups of correctly and incorrectly identified tokens is shown in Figures 4.8 and 4.9. Vowels carrying primary stress tend to be correctly identified more often than vowels carrying secondary stress. The predominance of primary-stressed tokens in the correctly identified group is most noticeable for /e/, perhaps reflecting the effect of stress on formant trajectory. An added, unforeseen effect may arise from the transconsonantal context. The set of secondary-stressed /e/'s contained more tokens with transconsonantal schwas and intervening flaps than the set of primary-stressed /e/'s. Flaps and labial consonants tend to allow transconsonantal influences between vowels, presumably because these consonants do not greatly constrain the tongue body.

The representation of vowels spoken in different styles in the groups of correctly and incorrectly identified tokens is shown in Figures 4.10 and 4.11. The nonsense style is most variable between the correctly and incorrectly identified groups. The vowel /e/ spoken in a nonsense word tends to be misidentified as /ɪ/. The vowel /ʌ/ spoken in a nonsense word tends to be misidentified as /ɛ/, whereas the vowel /ɛ/ spoken in a nonsense word tends to be correctly identified. However, the relevance to real speech of the effect of the nonsense style on vowel production and perception is questionable. The nonsense utterance does not appear in any written or mental dictionary and does not convey a meaning. Therefore, there is no criterion which is independent of the nonsense-style vowel's acoustic properties or perceptual impression by which to judge whether a speaker produced the vowel intended by the experimenter.

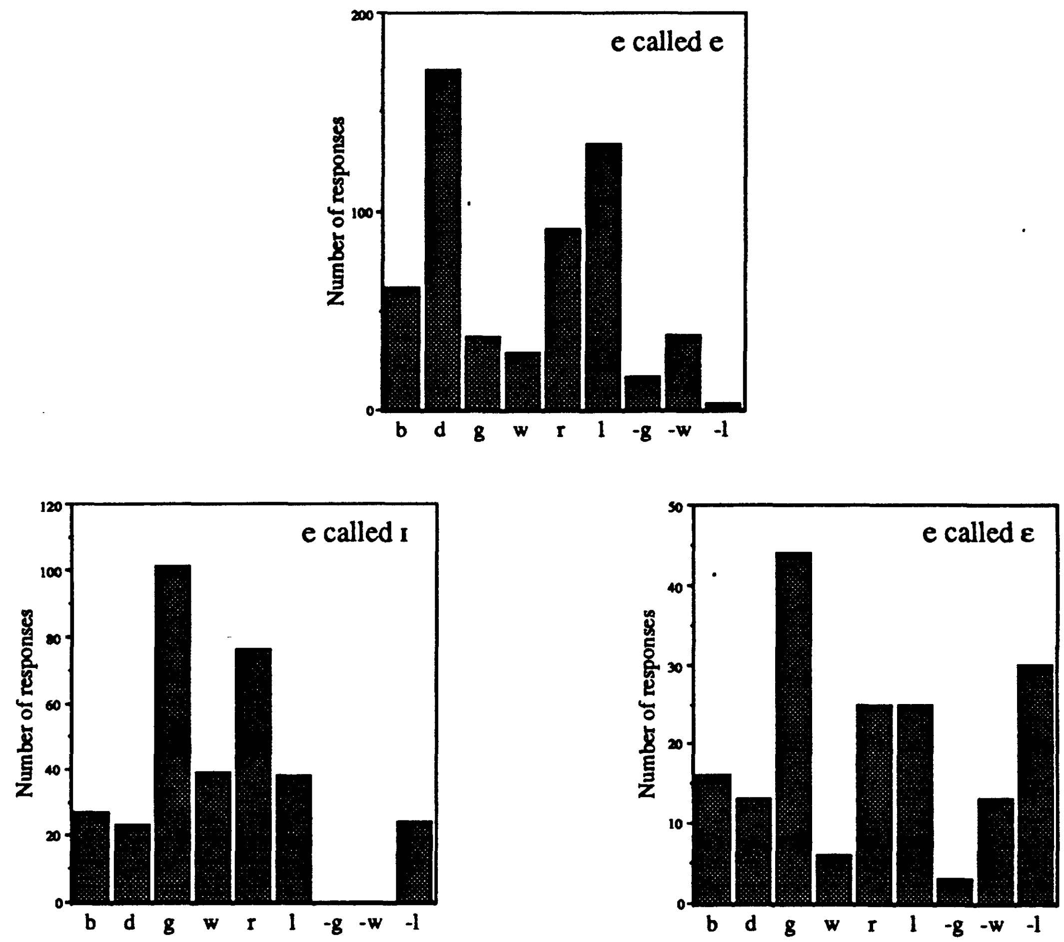


Figure 4.6: Representation of consonant contexts in groups of correctly and incorrectly identified /e/ tokens. -g, -w, and -l indicate final contexts; others are initial contexts. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. The relative heights of the bars within each graph shows that representation of contexts varies greatly between groups of correctly and incorrectly identified tokens.

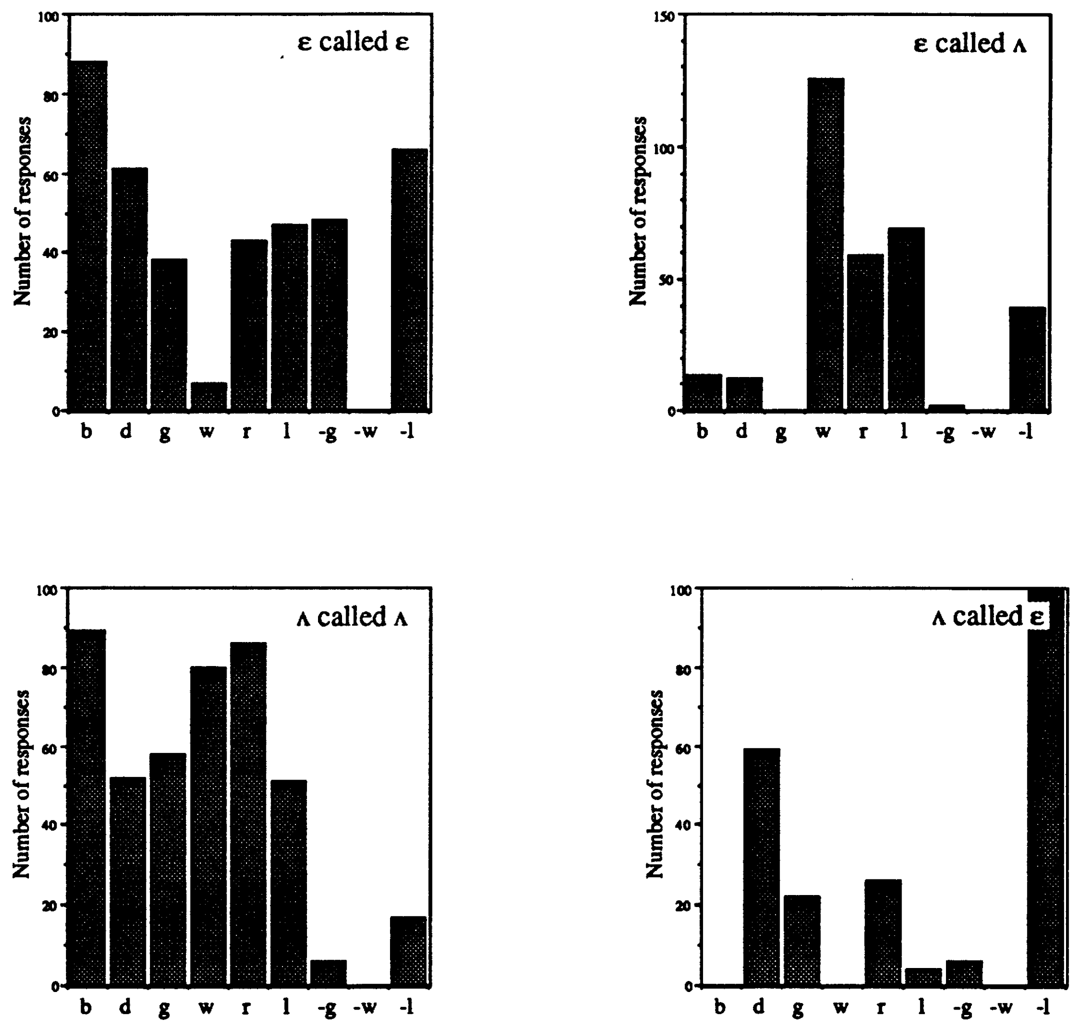


Figure 4.7: Representation of consonant contexts in groups of correctly and incorrectly identified /ɛ/ and /ʌ/ tokens. **-g**, **-w**, and -l indicate final contexts; others are initial contexts. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. The relative heights of the bars within each graph shows that representation of contexts varies greatly between groups of correctly and incorrectly identified tokens.

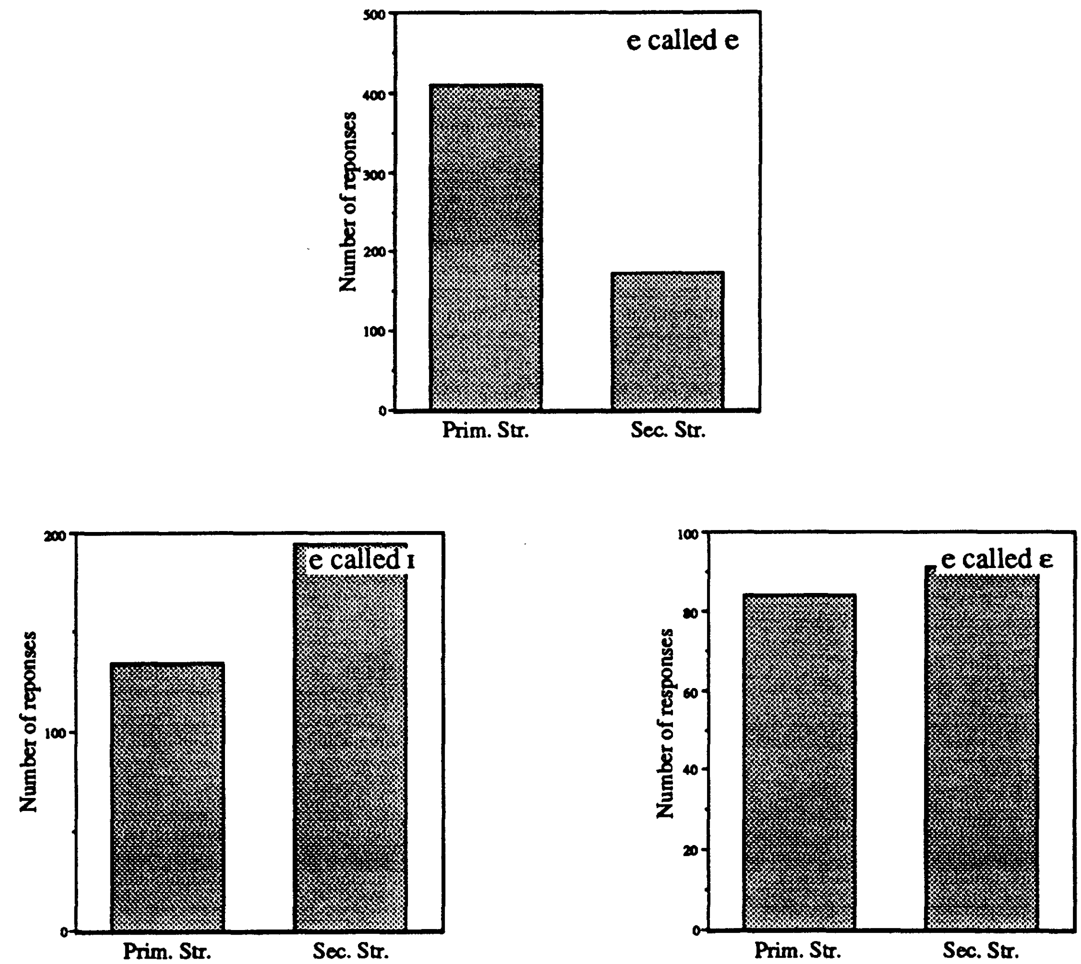


Figure 4.8: Representation of primary- and secondary-stressed vowels in groups of correctly and incorrectly identified /e/ tokens. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. Primary-stressed vowels correctly identified more often than secondary-stressed vowels.

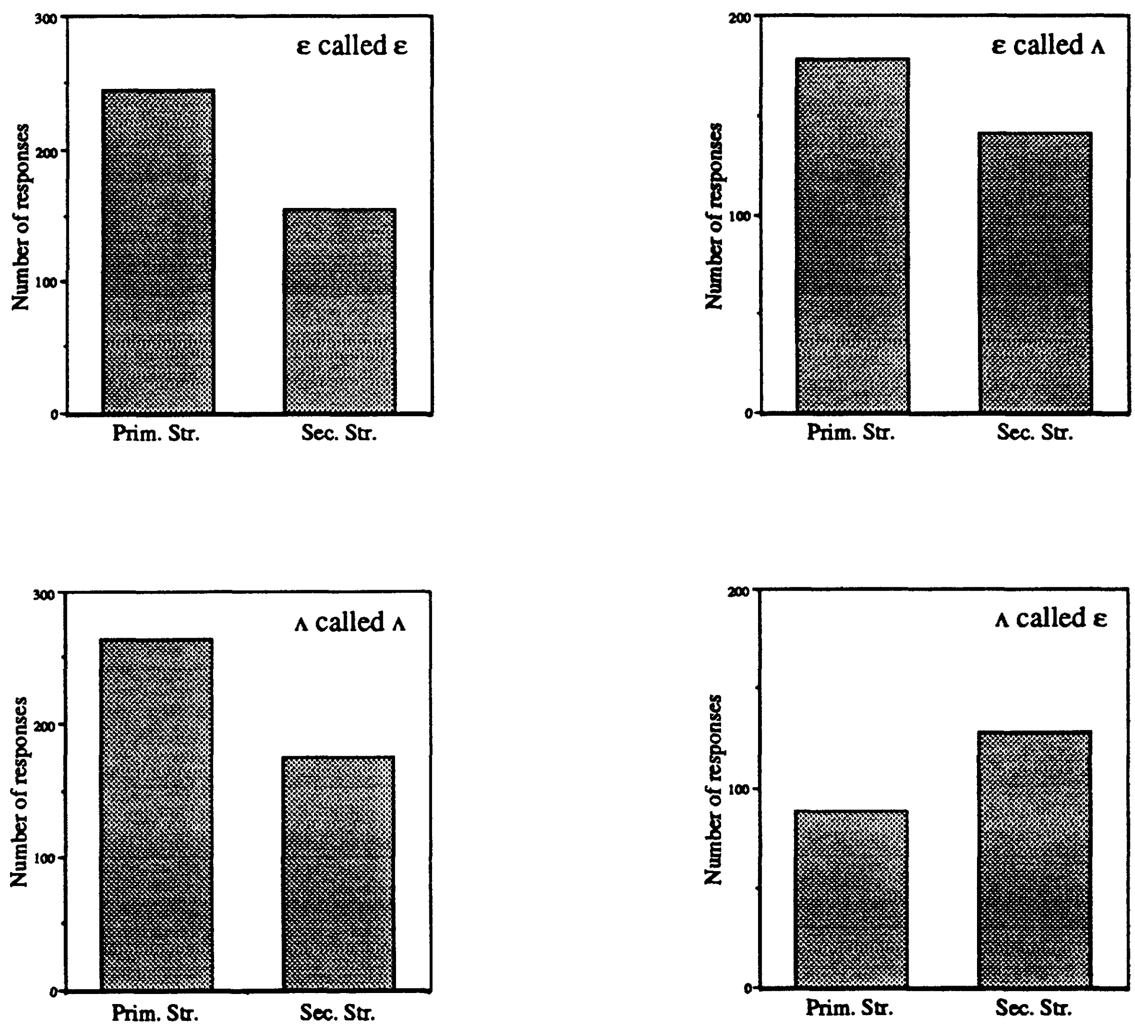


Figure 4.9: Representation of primary- and secondary-stressed vowels in groups of correctly and incorrectly identified /**ε**/ and /**ʌ**/ tokens. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. Primary-stressed vowels are correctly identified more often than secondary-stressed vowels.

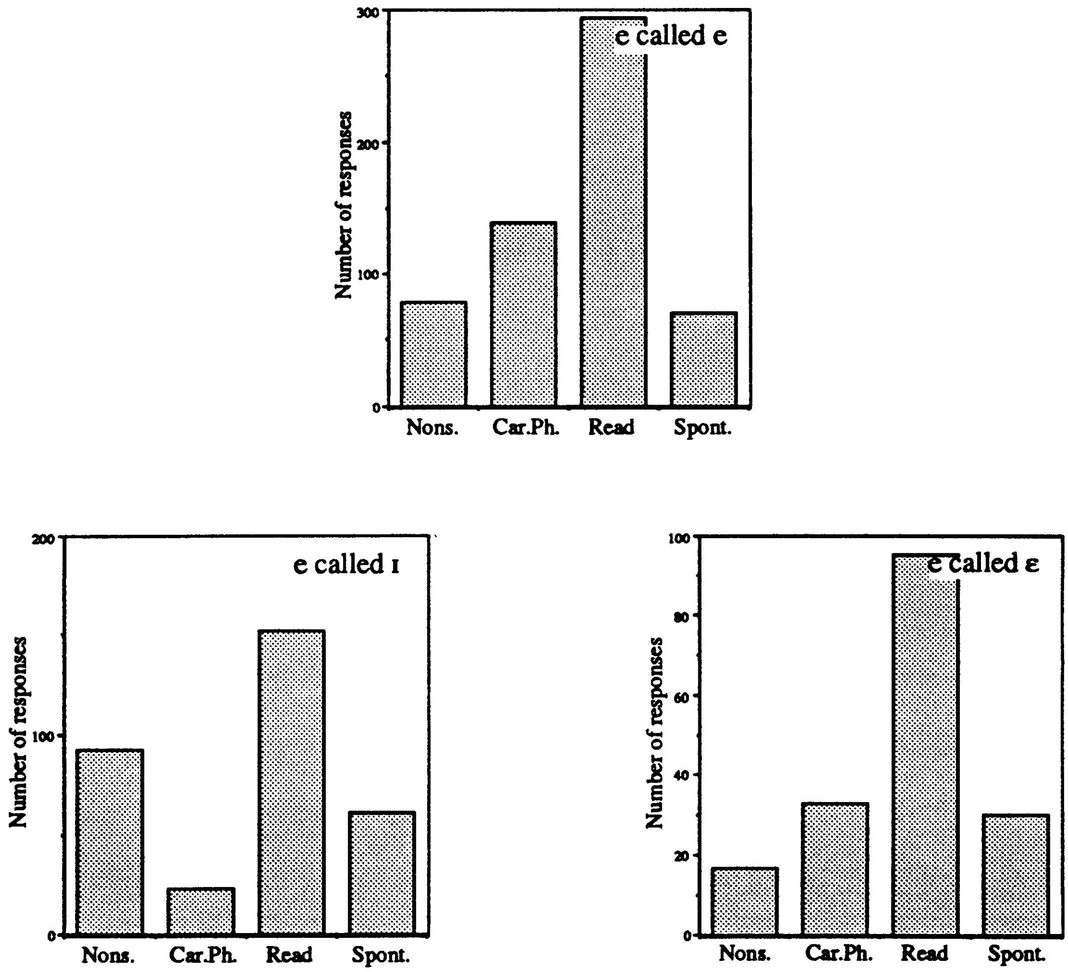


Figure 4.10: Representation of nonsense, carrier-phrase, read, and spontaneous speech styles in groups of correctly and incorrectly identified /e/ tokens. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. Representation of nonsense style varies between correctly and incorrectly identified groups.

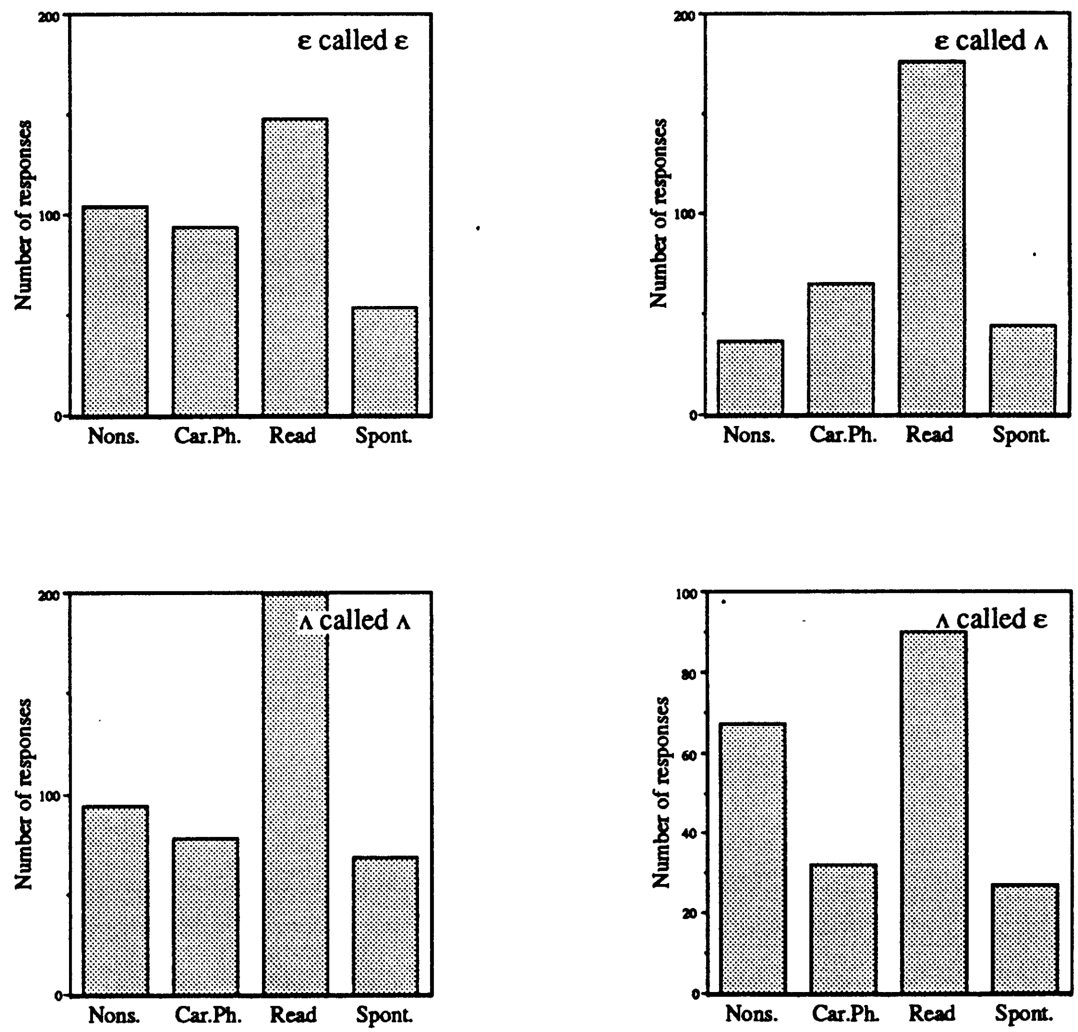


Figure 4.11: Representation of nonsense, carrier-phrase, read, and spontaneous speech styles in groups of correctly and incorrectly identified /ε/ and /ʌ/ tokens. Y-axis labelled "Number of responses" to indicate that each response (equivalently, each stimulus presentation) was considered a "token." Note that the y-axis scales are different for the three graphs. Representation of nonsense style varies between correctly and incorrectly identified groups.

4.3 Modelling the Pattern of Correct and Incorrect Identifications: Comparison between Performance of the Gaussian Classifier and Human Listeners

4.3.1 Agreement Between Identifications by the Gaussian Classifier and by the Listeners

One of the goals of the present study is to find the aspects of the vowel formant trajectory which are important for determining the vowel's identity. In the previous chapter, a representation of the vowel formant trajectory was sought which, when given as input to a statistical classifier, would result in the best performance. The representations which were tested included the vowel midpoint formant frequencies, alternative choices of one point along the vowel trajectory (e.g., the point at the F1 maximum), three points along the vowel trajectory, and three points and the vowel's duration. An alternative approach was to modify the midpoint based on the trajectory shape, simulating perceptual overshoot and undershoot effects. The best classification rate, using a Gaussian classifier, was achieved with the representation of the vowel by three points along the trajectory and duration. Further gains in performance were made if the consonant context was specified to be a stop or one of the liquid-glide class.

Now the aspects of the trajectory which are important for humans' identification of the vowel are sought. The representations of the vowels introduced in Chapter 3 are again given to the Gaussian classifier as input for training and testing. Percent agreement between the Gaussian classifier trained on the phonemic labels and each of two listeners was calculated. The two listeners were the ones who scored the highest and the lowest over the "no context" and CVC conditions taken together. Percent agreement would be the same as percent correct for the Gaussian classifier if the listener's responses are considered to be the "correct" answer rather than the experimenter's phonemic label.

Table 4.14 shows the percent agreement for between the Gaussian classifier and Listener 2 and Listener 5 in the single-speaker (JS) tests. In general, the vowel representations which resulted in the best performance by the Gaussian classifier in Chapter 3 agree with

Table 4.12: Percentage agreements between listeners for the single-speaker (JS) tests, "no context" condition. Listeners are coded by boldface numerals.

2	80.4			
3	75.4	78.0		
4	78.5	80.0	73.5	
5	78.5	74.8	71.8	77.0
	1	**2**	**3**	**4**

Table 4.13: Percentage agreements between listeners for the single-speaker (JS) tests, CVC condition. Listeners are coded by boldface numerals.

2	85.0			
3	77.3	78.5		
4	84.7	85.0	77.5	
5	84.0	78.9	74.2	82.6
	1	**2**	**3**	**4**

the listener's responses best. Data for the two listeners show the same trends. However, the percent agreement was consistently higher for the listener whose scores were higher in the identification tests. For comparison, percent agreement between listeners is shown in Tables 4.12 and 4.13.

The agreement with the Gaussian classifier is better on average for listening in the CVC condition than in the "no context" condition. Furthermore, the Gaussian model in which the stop and liquid-glide contexts are separated agrees with responses in both conditions better than the model in which the contexts are not separated. This fact supports the argument that the listeners are essentially responding the same way in both conditions but are able to identify vowels more consistently in the CVC condition. It seems that although the "no context" condition provides only impoverished context information, listeners still try to use context information in the same way as when more information is present.

Attempts to choose one point along the vowel trajectory which models the listeners' perception better than the durational midpoint were only slightly successful. Agreement

Table 4.14: Percent agreement between Gaussian classifier vowel identifications and responses of two individual listeners in single-speaker (JS) tests. "No context" condition shown in first four columns of data, CVC condition shown in last four columns. Gaussian was trained and tested on different representations of F1, F2, and F3 (listed in order of rows): midpoints, three points along trajectory, extrema of fitted parabolas, at F1 maximum, F1 average and extrema of F2 and F3, modified midpoints by the extrapolation factor resulting in best performance, midpoints with stops and liquids/glides separated, three points with stop and liquid-glide contexts separated. Including duration was tested also.

	Listener 2 "No context"		Listener 5 "No context"		Listener 2 CVC		Listener 5 CVC	
	w/o du.	w/ du.	w/o du.	w/ du.	w/o du.	w/ du.	w/o du.	w/ du.
Midpt.	71.1	74.8	62.6	65.8	72.6	74.5	68.5	71.0
3 pts.	73.7	76.0	63.7	65.7	73.7	75.9	70.4	72.6
Extrema	71.8	75.7	62.4	66.2	72.2	75.3	69.3	72.1
F1 Max.	68.9	73.5	61.1	65.4	68.5	71.4	65.5	69.6
F1 Ave.	73.4	74.9	63.8	66.0	73.8	75.2	70.3	71.4
Best Extr.	70.9	–	62.8	–	72.2	–	68.0	–
Sep.Cont. Midpt.	73.8	75.1	63.6	63.9	74.9	76.1	70.4	72.8
Sep.Cont. 3pts.	76.1	78.2	65.7	67.6	77.6	80.0	73.9	75.6

between the listeners' responses and the Gaussian model with the average of F1 and the extreme values of F2 and F3 as input was the best of the one-point representations. However, the improvement was only approximately 2% over the classifier using only the midpoint. Using the modified midpoint calculated from the extrapolation procedure simulating perceptual overshoot and undershoot did not improve agreement between the classifier and the listeners. Agreement improves consistently if the classifier is given three points from the trajectory and the vowel duration. The improvement in agreement adds to other evidence, discussed previously, which shows that aspects of the vowel trajectory beyond the midpoint affect the listeners' responses. However, an explicit description of how the trajectory information is used was not found in these experiments. The best approximation of a model of perception resulting from this study is one which separates liquid and glide contexts from other contexts and uses duration and several points along the vowel trajectory.

The Gaussian classifier's identifications and listeners' responses in the four-speaker tests were not compared in detail. Instead, the percent correct of the listeners on the four

Table 4.15: Comparison of percent correct for listeners and Gaussian classifier. Percent correct by listeners shown for "no context" and CVC conditions on first and second row for each speaker, respectively. Percent correct for classifier trained and tested on midpoints, three points and duration, and three points and duration with stop and liquid-glide contexts separated shown on first, second, and third row for each speaker, respectively. For both listeners and the classifier, RU's vowels tend to be easiest to identify and MP's tend to be the most difficult.

	Listeners	Gaussian Classifier
JS	72.3 ("no context") 77.1 (CVC)	74.1 (midpt.) 80.9 (3pts. and du.) 91.4 (contexts sep.)
RU	73.2 82.7	78.1 88.0 98.3
EE	71.7 81.7	69.1 87.3 93.3
MP	66.0 75.4	68.7 81.6 97.2

speakers' vowel tokens was compared with the overall performance of the Gaussian classifier on the four speakers. The data are shown in Table 4.15. The listeners' data are from the four-speaker tests, in which the listeners heard approximately 200 vowel tokens from each speaker. The Gaussian classifier data, previously shown in Chapter 3, are from the jackknifed models using the full data set, i.e., approximately 850 tokens for speaker JS and 200 tokens for each of the other speakers. For the listeners in both the "no context" and CVC conditions and the classifiers using most representations of the vowel data, speaker RU's vowels are easiest to identify and speaker MP's are most difficult to identify. This ordering is consistent also with the the amount of overlap in these speakers' F1-F2 vowel distributions seen in Chapter 3. However, the classifier which treats the stop and liquid-glide contexts separately achieves a higher score on MP's tokens than on JS's or EE's tokens. This lack of agreement suggests that the perceptual model proposed for JS above does not explain speaker differences.

4.3.2 Discussion: Why do Humans Perform Less Well Than the Statistical Classifier?

Overall, the human listeners do not identify the vowels as well as the best Gaussian classifier does, if the phonemic labels assigned by the experimenter are considered to be "correct." The goal of the experiments was to measure humans' ability to identify vowels occurring in meaningful utterances when they cannot identify the words. Ideally, the listeners would respond as if they had been asked to identify vowels presented in unfamiliar words in naturally spoken General American English sentences. Unfortunately, it is difficult to find words which are naturally spoken by some members of the General American dialect group and completely unfamiliar to other members. Controlling for consonant contexts and levels of stress in this small set of words would be very difficult.

The experimental procedure may have had flaws which caused some listeners' errors which would not arise in the ideal case described above. The vowels, which were excised from running speech, would never occur in such a form in natural speech situations. In fact, the lack of speech context for the vowels may cause the human auditory system to respond to the signal in ways which only occur at speech onsets and offsets. In natural situations, speech onsets and offsets occur much less often than in the identification tests. As described in Chapter 2, a procedure was tested whereby a processed, unrecognizable version of the speech signal surrounding the vowel was presented with the vowel as a more natural context. The context did not sound natural, and the problem requires more study. The limitations of the task may have made the problem easier for the classifier but not for the humans. There were only five vowels, and the vowels were identified in a speaker-dependent manner. Human listeners cannot eliminate their knowledge of other speakers and vowels and therefore may not be able to take advantage of the task's limitations. Also, the listeners did not receive any feedback to teach them the "correct" responses, since this kind of feedback would make the task even less natural. A simpler distracting factor was the repetitiveness of the task, which may have caused the listeners to make errors due to inattention.

Even if the ideal experimental procedure were to be found, the task of vowel identification itself may be different from the demands of natural speech understanding. The identification task applied to natural speech would entail segmenting the utterance and identifying every feature of each segment. It is possible that segmenting and identifying phonemes is unnecessary for a listener to decode the words or to understand the meaning of an utterance. Instead, the listener may access words or phrases by identifying some but not all features of the utterance, in time sequence but without strict segmentation. Because of the above considerations, caution must be taken in making conclusions about human speech recognition on the basis of the results of tests in which listeners are required to identify individual speech sounds.

One conclusion is clear: The human error rate is not wholly due to lack of information in the acoustic signal. Whether because of flaws in the experimental procedure or because of an inherent inability of humans to perform the vowel identification task, even a simple Gaussian classifier given less acoustic information can identify vowels more consistently than humans. The optimal classifier given all of the available acoustic information would perform even better than the Gaussian classifier. The human error rates found in the present study, which are comparable to error rates found in previous experiments with continuous speech (e.g., Koopmans-van Beinum, 1980) cannot be taken as benchmarks for performance of automatic recognition by machine. Automatic procedures can apparently label vowels more consistently with a phonemic labelling procedure than humans, and this higher performance may be able to partially compensate for any deficiencies of the automatic procedure in using higher level language information.

Chapter 5

Conclusions

5.1 Summary and Interpretation of Results

The present study extends the existing body of work on vowels in several ways. Three factors – consonantal context, lexical stress, and speech style – which have been previously shown to affect the acoustics of vowels separately, are examined and compared on the same database. In the past, isolated vowels, vowels from nonsense words, and vowels from words in carrier phrases have been widely studied. In the present study, vowels are taken from more natural speech styles, including a read story and spontaneous speech. In addition to describing the vowels in terms of their midpoint formant frequencies, as has often been done previously, the present study attempts to characterize the vowels in terms of some aspects of their formant trajectories. Finally, the vowels' acoustic properties are related to the ability of human listeners to identify the vowels.

The database consists of the vowels /i/, /ɪ/, /e/, /ɛ/, and /ʌ/. Approximately 850 vowel tokens were collected from one speaker, and 200 tokens were collected from each of three additional speakers. The consonant contexts studied were /b/, /d/, /g/, /w/, /r/, and /l/. Only primary and secondary levels of lexical stress were considered. Schwa vowels were excluded from the database. The speech styles considered were nonsense words in a carrier phrase, real words in a carrier phrase, a read story, and spontaneous speech. The spontaneous speech was elicited by interrupting the speakers at intervals while they were reading the story and asking them to retell the story.

Consonant context was found to affect the vowel midpoints more than lexical stress and speech style. The direction and magnitude of the formant frequency shifts found were consistent with findings of previous studies (Stevens and House, 1963; Lehiste, 1962). The liquid and glide contexts, /**w**/, /ɪ/, and /l/, lowered the F2 frequency of front vowels, especially lax front vowels, on the order of one Bark relative to the F2 frequencies when the same vowels are adjacent to stop consonants. That is, the consonants /**w**/, /ɪ/, and /l/, tend to back the front vowels. This result might have been expected, because the consonants /**w**/, /ɪ/, and /l/ constrain the tongue body to be [+back]. Although the present study did not include the glide /**y**/, which constrains the tongue body to be [-back], it is expected that /**y**/ would also affect vowels greatly, tending to front back vowels. Shifts for F1 tended to be smaller than shifts in F2, even on a Bark scale, and were less consistent across speakers. That is, it seems that the effect on vowel height of the consonant contexts studied is not large. However, measurement error may have obscured consistent trends in F1 shifts, since the error was the order of the size of the F1 shifts.

The formant frequency midpoints and durations of vowels carrying primary stress were shown to differ only slightly on average from the acoustics of vowels carrying secondary stress, if the other factors were held constant. Vowels in continuous read speech also differed only slightly on average from vowels in spontaneous speech. Previous studies have shown greater effects of these factors (Koopmans-van Beinum, 1980; Delattre, 1969). However, special characteristics of the database of the present study must be kept in mind. The intention was to exclude from the database reduced and reducible vowels, as determined by phonological criteria discussed in the introduction. The reduced vowel, or schwa, was considered to be in a separate phonemic class from the other vowels. Reduced and reducible vowels may be more affected by stress and style than the stressed vowels, and previous studies which included schwas labelled as other vowels may have shown a greater effect of these factors for this reason. An alternative way of interpreting the result of the present study is to note that vowel variability decreases if labelling is done carefully to separate schwas from other vowels.

If the formant frequencies and durations of primary- and secondary-stressed vowels truly do not differ much, it may be postulated that stress is not differentiated in the movements of the supraglottal system. By this hypothesis, levels of stress would be differentiated by laryngeal control only, and the acoustic effects would be changes in amplitude and fundamental frequency rather than changes in formant frequency.

However, there may have been differences between the formant frequencies of the primary- and secondary-stressed vowels which were obscured by the averaging. Since most of the words were taken from sentence contexts, stress shift may have occurred such that many of the vowels carrying secondary lexical stress received phrasal prominence. The acoustic correlates of a syllable carrying phrasal prominence may be similar to the correlates for primary stress in citation form. Also, there may be some evidence that context (consonantal and transconsonantal) and stress interact.

With regard to speech style, the present study of American English found a smaller effect than has been reported in studies of other languages and dialects, suggesting that the effect may be language- and dialect-dependent. However, it must be noted that there are many styles of speech which were not included in the present study. Isolated vowels and vowels in monosyllabic isolated words are acoustically different from vowels in continuous speech. These two styles were omitted from the present study because they are less natural than continuous styles of speech. A free conversational style of speech may have resulted in more vowel centralization than the retold-story style of spontaneous speech elicited in the present study. The conversational style was omitted because it would have been very difficult to elicit words including vowels with the required consonant context and level of lexical stress.

Data on formant trajectories have been compiled. Variation in characteristics of the formant trajectories seems to have perceptual consequences. For example, the F2 of 65% of the /**e**/ tokens for one of the speakers of the database has a late rise signifying the presence of a /**y**/ offglide, which is typical for /**e**/ in American English. The other tokens do not have the characteristic offglide, and they tend to be misidentified as lax vowels by listeners when they are excised from their context.

In general, the data show that variations in vowel midpoint formant frequencies, durations, and trajectory shapes are correlated with the perception of the vowel by human listeners. For example, /**ɛ**/ tokens which have F1-F2 midpoint values typical of /**ʌ**/ tend to be identified as /**ʌ**/, and /**e**/ tokens which are short and lack a /**y**/ offglide, typical characteristics of lax vowels, tend to be misidentified as lax vowels.

Aspects of the trajectories which are important for characterizing the vowel were sought. The approach was taken of using the trajectory to derive a representation of the vowel by one point per formant, a modified "midpoint." Performance by a Gaussian classifier was the criterion used to evaluate different representations of the vowels. If parabolas were fit to the trajectories, and the frequency at the extremum (maximum or minimum) was found for each formant and used as input for the classifier, performance was slightly better than if the durational midpoints were used as input. If the effect of perceptual overshoot for F2 and perceptual averaging for F1 was simulated, performance by the Gaussian classifier was better still. However, the best performance was achieved if points from the raw data – the quarter-point, midpoint, and three-quarter point of the trajectory and the duration – were used as input to the classifier. The improved performance with the raw data over the modified midpoints shows that not all of the significant aspects of the trajectory have been captured in a one-point representation. It may be that a new one-point representation could be found which would result in as high performance as the raw data. Alternatively, it may be necessary to use more than a modified midpoint to fully characterize a vowel.

Of all the representations used as input to the statistical classifier, points from the raw data also result in the best agreement of the classifier with the human performance. This result suggests that the listener uses all aspects of the vowel trajectory – the midpoint formant frequencies, the duration, and the shape – to deduce what the intended vowel of the speaker was. If the classifier is also allowed to train and test on vowels in stop and liquid-glide contexts separately, agreement with the listeners' responses (and performance in the conventional sense, i.e., agreement with the phonemic labels) improves further. The improvement due to separating the contexts suggests that humans perform vowel identification in a context-dependent manner. That is, the listener seems to have mental rules which state that the realization of vowel targets will be different, depending on the context.

The apparent context dependency raises the question of whether the listeners' and speakers' mental rules state that only the realization of the vowel changes, or whether the intended vowel itself changes (through a phonological rule). The results of the present study cannot argue for one of these alternatives over the other.

5.2 Implications

The results of the present study have implications for current speech synthesis and speech recognition systems. Since current systems are required to recognize spontaneous speech and generate responses in a conversational style, data on spontaneous speech are needed. From the results of the present study, it appears that non-reduced vowels in read speech do not differ much from those in spontaneous speech, so that data from previous studies on carrier-phrase and read speech are still applicable. Furthermore, it seems that the acoustics of primary- and secondary-stressed vowels can be treated the same way, at least to a first approximation, in these applications. These simplifications may need to be revised if future work shows that stress shift and other sentence- and discourse-level factors affect the vowels noticeably. That is, it may turn out to be necessary to model the differences between primary- and secondary-stressed vowels or read and spontaneous vowels, but many other factors need to be taken into account. In contrast, the large effect of consonant context on vowels is apparent even without considering other factors, and it is clear that modelling this effect is necessary for applications such as speech synthesis and speech recognition.

The present findings have implications for the understanding of vowel perception. The Gaussian classifier achieves higher accuracy than human listeners in identifying the vowels of this database. The differential may arise from experimental problems, such as the artificial nature of the task, the introduction of artifacts in the auditory response to the modified speech signal or inattention of the listeners. However, assuming that whole differential is not due to such artifacts, the result suggests that human listeners do not use all of the available acoustic information in the optimal way to identify vowels, and that they do not need to identify vowels perfectly in order to recognize words in running speech. That is, the results of the present study suggest that lexical access can be performed successfully without a complete or completely correct specification of the vowel.

The theory of underspecification states that some distinctive features are left unspecified for certain phonemes in the speakers' and listeners' mental representations of a word. (For a discussion of phonological and phonetic underspecification theory, see Keating, 1988.) In the discussion which follows, the term "underspecification" will be used in a looser sense, including ideas from formal underspecification theory but also including other considerations. Factors which determine which phonemes can be underspecified include the inventory of phonemes in a particular language and the lexicon of the language. For example, it has been proposed that since all phonemically round vowels in English are [+back], the backness of English vowels is unspecified if rounding is specified. Another major source of redundancy arises from phonotactic constraints (e.g., in a three-segment syllable onset, the first segment must be /**s**/). The influence of the lexicon arises by cataloguing the presence or absence of minimum pairs which are confusable. For example, it may be argued that the backness of the vowel /**ɛ**/ in the word "well" does not need to be specified, since there is no other word in English which is pronounced /**wʌl**/. In other words, pronouncing the vowel in "well" as /**ɛ**/ or as /**ʌ**/, which has the same features as /**ɛ**/ except for backness, would be equally acceptable, as far as identifying the word is concerned. Higher-level factors may also affect the requirements for specification of the features in the mental lexicon. If the syntactic structure makes only one word of a minimum pair likely, then underspecification of features may be allowed. For example, a speaker saying "I will ..." may consider the vowel "will" to be highly underspecified, since the similar-sounding words "well, "wool," and "we'll" would not form a grammatical sentence. Semantic factors may also affect the requirements. Features for words in highly predictable contexts may not need to be represented accurately in the signal. For example, some features of the vowel in the word "wool" in "wool for knitting" may not be adequately represented because none of the similar-sounding words would make sense in that phrase.

The notion of underspecification is not the only possible explanation for successful lexical access in spite of errors in listener identification of vowels, however. The fact that humans make errors in vowel identification but can still identify words may only mean that the lexical access process can recover from errors, although in some cases only with higher-level information. In either case, the conclusion is that perfect identification of vowels is not necessary for lexical access.

5.3 Future Work

The results of this study should be confirmed or revised in light of an investigation of the full American English vowel set. Some of the results are vowel-dependent. In the present study, for example, speech style seems to affect tense vowels more strongly than lax vowels. (See also Koopmans-van Beinum, 1989, which shows differing amounts of shift due to speech style for different vowels in Dutch.) The low vowels, /æ/ and /ɑ/, which are articulated with large movements of the jaw, a sluggish articulator, may be more influenced by stress and style than the vowels included in this study. Retroflexed and rounded vowels are also likely to be affected differently by the factors, since the articulatory correlates of these features are different from those of the features investigated in the present study. The articulatory correlate is tongue body position for vowel height and backness. The articulatory correlate is unclear for tenseness but is probably a combination of muscular effort and timing of the movements. The articulatory correlate for retroflexion is tongue shape, and the correlate for roundness is lip rounding.

Perceptual effects may also be vowel-dependent. Huang (1987) suggested that the perceptual processing of the formant trajectory may be frequency-dependent. This hypothesis was considered in the modelling described in Chapter 3, but vowels in some areas of the vowel quadrilateral were not available. For example, no vowel with an extremely high F1, such as /æ/ or /ɑ/, was in the database.

A full vowel set would also allow better modelling of vowel perception by humans. Humans expect many more vowels in natural speech than appeared in the database. The knowledge of other vowels may have made the identification tests more confusing. The limited vowel set may have made the tests more artificial than if a full set had been used. The Gaussian classifier in the present study only had to distinguish among five vowels. With a full set, the Gaussian classifier would have more confusable vowel pairs. In particular, the pairs /ɛ/-/æ/ and /ʌ/-/ɑ/ would be likely to be confused. The performance of humans and the classifier may be more similar when a full vowel set is used than when a limited vowel set is used.

Reduced and reducible vowels should be studied. The effect of factors which have been shown to affect vowels should be studied for schwas. Rules must be found for predicting when a vowel in a word will be reduced from a canonical representation of the word, such as the dictionary pronunciation. Factors which could affect the rule might include the consonant context, the speech style and the particular speaker.

The spontaneous speech style does not seem to affect non-reduced vowels much differently than other speech styles, but other aspects of spontaneous speech could be very different from read speech. These aspects, such as prosody, reduction of consonants, and pronunciation of schwas and function words should be studied further.

Finally, the formant trajectories must be examined more closely to quantify the effects of various factors on trajectory shapes. Also, now that the effects of formant trajectory shapes have been found to be noticeable in the perception of naturally-produced vowels, the effects should be quantified by conducting identification tests with synthesized stimuli.

Bibliography

[1] Assmann, P., Nearey, T., and Hogan, J. (1982): "Vowel identification: Orthographic, perceptual, and acoustic aspects," *JASA* **71**(4), pp. 975-989.

[2] Becker, R., Chambers, J., and Wilks, A. (1988): *The New S Language, A Programming Environment for Data Analysis and Graphics*, AT&T Bell Laboratories, Wadsworth & Brooks/Cole Advanced Books & Software, CA.

[3] Carlson, R., Granström, B., and Klatt, D. (1979): "Vowel perception: The relative perceptual salience of selected acoustic manipulations," STL-QPSR 3-4/1979, pp. 73-83.

[4] Chambers, J., Cleveland, W., Kleiner, B., and Tukey, P. (1983): *Graphical Methods for Data Analysis*, Wadsworth International Group, Belmont, CA, and Duxbury Press, Boston, MA, pp. 21-24.

[5] Crystal, T. and House, A. (1988): "The duration of American-English vowels: An overview," *Journal of Phonetics* **16**, pp. 263-284.

[6] Cyphers, D., Kassel, R., Kaufman, D., Leung, H., Randolph, M., Seneff, S., Unverferth, III, J., Wilson, T., and Zue, V. (1986): "The development of speech research tools on MIT's lisp machine-based workstations," *Proceedings of the Speech Recognition Workshop* (sponsored by DARPA), Palo Alto, CA, pp. 110-115.

[7] Delattre, P. (1969): "The general phonetic characteristics of languages. An acoustic and articulatory study of vowel reduction of four languages," Final Report, University of California, Santa Barbara, CA, USA.

[8] Delattre, P., Liberman, A., and Cooper, F. (1955): "Acoustic loci and transitional cues for consonants," *JASA* **27**(4), pp. 769-773.

[9] Di Benedetto, M.-G. (1987): "An acoustical and perceptual study on vowel height," Ph.D. thesis, Università degli Studi di Roma 'La Sapienza', Rome, Italy.

[10] Duda, R., and Hart, P. (1973): *Pattern Classification and Scene Analysis*, John Wiley & Sons, New York, pp. 44-49, 114-118.

[11] Fant, G. (1970): *Acoustic Theory of Speech Production*, Mouton, The Hague.

[12] Fant, G. (1973): *Speech Sounds and Features*, MIT Press, Cambridge, MA, p. 192.

[13] Fant, G., and A. Risberg (1963): "Auditory matching of vowels with two formant synthetic sounds," STL-QPSR 4/1963, pp. 7-11.

[14] Gillick, L., and Cox, S. (1989): "Some statistical issues in the comparison of speech recognition algorithms," *Proceedings of ICASSP89*, Glasgow, Scotland, pp. 532-535.

[15] Huang, C. (1985): "Perceptual correlates of the tense/lax distinction in General American English," Master's thesis, MIT, Cambridge, MA, USA.

[16] Huang, C. (1987): "Perception of first and second formant frequency trajectories in vowels," *Proceedings of the 11th International Congress on Phonetic Sciences*, August 1987, Tallinn, ESSR, USSR.

[17] Hunnicutt, S. (1985): "Intelligibility versus redundancy - conditions of dependency," *Language and Speech* **28**, pp. 47-56.

[18] Hunnicutt, S. (1987): "Acoustic correlates of redundancy and intelligibility," *Proceedings of the 11th International Congress on Phonetic Sciences*, August 1987, Tallinn, ESSR, USSR.

[19] Jakobson, R., Fant G. and Halle, M. (1969): *Preliminaries to Speech Analysis*, MIT Press, Cambridge, MA, USA.

[20] Jenkins, J., Strange, W., and Edman, T. (1983): "Identification of vowels in 'vowelless' syllables," *Perception & Psychophysics* **34**(5), pp. 441-450.

[21] Johnson, R., and Wichern, D. (1988): *Applied Multivariate Statistical Analysis, Second Edition*, Prentice Hall, NJ, pp. 210-243.

[22] Kassel, R. (1986): "Aids for the design, acquisition, and use of large speech databases," S.B. thesis, MIT, Cambridge, MA, USA.

[23] Keating, P. (1988): "Underspecification in phonetics," *Phonology*, **5**, pp. 275-292.

[24] Koopmans-van Beinum, F. (1980): "Vowel contrast reduction, An acoustic and perceptual study of Dutch vowels in various speech conditions" Ph.D. thesis, University of Amsterdam, Amsterdam, The Netherlands.

[25] Koopmans-van Beinum, F. (1989): "The role of 'given' and 'new' in the production and perception of vowel contrasts in read text and in spontaneous speech," *Eurospeech 89*, Paris, France, pp. 113-116.

[26] Kuwahara, H., and Sakai, H. (1972): "Perception of vowels and CV-syllables segmented from connected speech," *J. Acoust. Soc. Japan* **28**, pp. 225-234.

[27] Ladefoged, P., Kameny, I., and Brackenridge, W. (1976): "Acoustic effects of style of speech," *JASA* **59**(1), pp. 228-231.

[28] Lehiste, I. (1962): "Acoustical characteristics of selected English consonants," Report No. 9 for the Air Force Office of Scientific Research, Communication Sciences Laboratory, University of Michigan, Ann Arbor, MI, USA.

[29] Lehiste, I., and Peterson, G. (1961): "Transitions, glides, and diphthongs," *JASA* **33**(3), pp. 268-277.

[30] Leung, H. (1989): "The use of artificial neural networks for phonetic recognition," Ph.D. thesis, MIT, Cambridge, MA, USA, p. 147.

[31] Liberman, M., and Prince, A. (1977): "On stress and linguistic rhythm," *Linguistic Inquiry* 8, pp. 249-336.

[32] Lieberman, P. (1963): "Some effects of semantic and grammatical context on the production and perception of speech," *Language and Speech* **6**, pp. 172-187.

[33] Lindblom, B. (1963): "Spectrographic study of vowel reduction," *JASA* **35**(11), pp. 1773-1781.

[34] Lindblom, B. (1968): "On the production and recognition of vowels," Ph.D. thesis, University of Lund, Lund, Sweden.

[35] Lindblom, B., and Studdert-Kennedy, M. (1967): "On the role of formant transitions in vowel recognition," *JASA* **42**(4), pp. 830-843.

[36] Maeda, S. (1976): "A characterization of American English intonation," Ph.D. thesis, MIT, Cambridge, MA, USA.

[37] Magen, H. (1984): "Vowel-to-vowel coarticulation in English and Japanese," Paper presented at the 107th Meeting of the Acoustical Society of America, Norfolk, Virginia, USA.

[38] Magen, H. (1989): "An acoustic study of vowel-to-vowel coarticulation in English," Ph.D. thesis, Yale University, New Haven, CT, USA.

[39] Manuel, S., and Krakow, R. (1984): "Universal and language particular aspects of vowel-to-vowel coarticulation," Haskins Laboratories: Status Report on Speech Research SR-77/78, pp. 69-78.

[40] Miller, R. (1953): "Auditory tests with synthetic vowels," *JASA* **25**(1), pp. 114-121.

[41] Nearey, T., and Assmann, P. (1986): "Modeling the role of inherent spectral change in vowel identification," *JASA* **80**(5), pp. 1297-1308.

[42] Nord, L. (1986): "Acoustic studies of vowel reduction in Swedish," STL-QPSR 4/1986, pp. 19-36.

[43] Öhman, S. (1966): "Coarticulation in VCV utterances: Spectrographic measurements," *JASA* **39**(1), pp. 151-168.

[44] Peterson, G. and Barney, H. (1952): "Control methods used in a study of vowels," *JASA* **24**(2), pp. 175-184.

[45] Pierrehumbert, J. (1980): "The phonology and phonetics of English intonation," Ph.D. thesis, MIT, Cambridge, MA, USA.

[46] Pitrelli, J. (1990): "Hierarchical modeling of phoneme duration: Application to speech recognition," Ph.D. thesis, MIT, Cambridge, MA, USA, p. 103.

[47] Port, R. (1981): "Linguistic timing factors in combination," *JASA* **69**(1), pp. 262-274.

[48] Schroeder, M., Atal, B., and Hall, J. (1979): "Objective measure of certain speech signal degradations based on masking properties of human auditory perception," in B. Lindblom and S. Öhman (eds.), *Frontiers of Speech Communication Research*, Academic Press, London, pp. 217-229.

[49] Shockey, L. (1973): "Phonetic and phonological properties of connected speech," Ph.D. thesis, The Ohio State University, Columbus, OH, USA.

[50] Stålhammar, U., Karlsson, I., and Fant, G. (1973): "Contextual effects on vowel nuclei," STL-QPSR 4/1973, pp. 1-18.

[51] Stevens, K., and House, A. (1963): "Perturbation of vowel articulations by consonantal context: An acoustical study," *Journal of Speech and Hearing Research* **6**, pp. 111-128.

[52] Stevens, K., House, A., and Paul, A. (1966): "Acoustic description of syllabic nuclei: An interpretation in terms of a dynamic model of articulation," *JASA* **40**(1), pp. 123-132.

[53] Strange, W., Verbrugge, R., Shankweiler, D., and Edman, T. (1976): "Consonant environment specifies vowel identity," *JASA* **60**(1), pp. 213-244.

[54] Swaffield, J., Shearme, J., and Holmes, J. (1961): "Some measurements on the vowel sounds of conversational speech," Joint Speech Research Unit of the British Post Office, Eastcote.

[55] Tiffany, W. (1953): "Vowel recognition as a function of duration, frequency modulation and phonetic context," *J. Speech Hear. Disord.* **18**, pp. 289-301.

[56] Traunmüller, H. (1981): "Perceptual dimension of openness in vowels," *JASA* **69**(5), pp. 1465-1475.

[57] Van Son, R. and Pols, L. (1989): "Comparing formant movements in fast and normal rate speech," *Eurospeech 89*, Paris, France, pp. 665-668.

[58] Verbrugge, R., Strange, W., Shankweiler, D., and Edman, T. (1976): "What information enables a listener to map a talker's vowel space?" *JASA* **60**(1), pp. 198-212.

[59] Wang, M., and Bilger, R. (1973): "Consonant confusions in noise: a study of perceptual features," *JASA* **54**(5), pp. 1248-1266.

[60] *Webster's Ninth New Collegiate Dictionary* (1985), F. Mish, Editor in Chief, Merriam-Webster Inc., Springfield, MA, USA.

[61] Zwicker, E. (1961): "Subdivision of the audible frequency range into critical bands (Frequenzgruppen)," *JASA* **33**(1), pp. 248-249.

Appendix A

Corpus

The corpus of speech data is described in detail below. In the recording session, the subjects did the tasks in the following order: read and retell the story, read the nonsense words, read the real words in a carrier phrase, read /hVd/ words in a carrier phrase.

A.1 "Canonical Words"

The speakers were asked to read /hVd/ words in a carrier phrase. The /hvd/ word and the carrier phrase frame were chosen to make the data comparable with those from previous studies. The experimenter first went through the list with the speaker, explaining some sound-spelling correspondences.

Say a magenta heed <u>again</u>

Say a magenta hid <u>again</u>.

Say a magenta haid <u>again</u>.

Say a magenta head <u>again</u>.

Say a magenta hud <u>again</u>.

A.2 Nonsense Words

Subjects were instructed to read the following sentences from cards (one sentence per card, in randomized order), pronouncing the nonsense word similarly to "dedicated." Therefore, the syllable which contains the vowel of interest should carry primary stress. The word "once" was to carry sentential stress. The experimenter first went through some sample sentences with the subject, explaining sound-spelling correspondences with example words (e.g. the first vowel in "budacated" is the vowel in "butt").

Say a magenta beedacated <u>once</u>.

Say a magenta bidacated <u>once</u>.

Say a magenta baidacated <u>once</u>.

Say a magenta bedacated <u>once</u>.
Say a magenta budacated <u>once</u>.
Say a magenta deedacated <u>once</u>.
Say a magenta didacated <u>once</u>.
Say a magenta daidacated <u>once</u>.
Say a magenta dedacated <u>once</u>.
Say a magenta dudacated <u>once</u>.
Say a magenta geedacated <u>once</u>.
Say a magenta gidacated <u>once</u>.
Say a magenta gaidacated <u>once</u>.
Say a magenta gedacated <u>once</u>.
Say a magenta gudacated <u>once</u>.
Say a magenta deegacated <u>once</u>.
Say a magenta digacated <u>once</u>.
Say a magenta daigacated <u>once</u>.
Say a magenta degacated <u>once</u>.
Say a magenta dugacated <u>once</u>.
Say a magenta weedacated <u>once</u>.
Say a magenta widacated <u>once</u>.
Say a magenta waidacated <u>once</u>.
Say a magenta wedacated <u>once</u>.
Say a magenta wudacated <u>once</u>.
Say a magenta deewacated <u>once</u>.
Say a magenta daywacated <u>once</u>.
Say a magenta reedacated <u>once</u>.
Say a magenta ridacated <u>once</u>.
Say a magenta raidacated <u>once</u>.
Say a magenta redacated <u>once</u>.
Say a magenta rudacated <u>once</u>.
Say a magenta leedacated <u>once</u>.
Say a magenta lidacated <u>once</u>.
Say a magenta laidacated <u>once</u>.
Say a magenta ledacated <u>once</u>.
Say a magenta ludacated <u>once</u>.

Say a magenta deelacated once.

Say a magenta dilacated once.

Say a magenta dailacated once.

Say a magenta delacated once.

Say a magenta dulacated once.

The procedure for the following sentences was the same as for the previous sentences, with the exception that the nonsense word was pronounced similarly to "dedicated." Therefore, the syllable which contains the vowel of interest should carry secondary stress.

Say a magenta beedacation once.

Say a magenta bidacation once.

Say a magenta baidacation once.

Say a magenta bedacation once.

Say a magenta budacation once.

Say a magenta deedacation once.

Say a magenta didacation once.

Say a magenta daidacation once.

Say a magenta dedacation once.

Say a magenta dudacation once.

Say a magenta geedacation once.

Say a magenta gidacation once.

Say a magenta gaidacation once.

Say a magenta gedacation once.

Say a magenta gudacation once.

Say a magenta deegacation once.

Say a magenta digacation once.

Say a magenta daigacation once.

Say a magenta degacation once.

Say a magenta dugacation once.

Say a magenta weedacation once.

Say a magenta widacation once.

Say a magenta waidacation once.

Say a magenta wedacation once.

Say a magenta wudacation once.

Say a magenta deewacation once.

Say a magenta daywacation once.

Say a magenta reedacation once.

Say a magenta ridacation once.

Say a magenta raidacation once.

Say a magenta redacation once.

Say a magenta rudacation once.

Say a magenta leedacation once.

Say a magenta lidacation once.

Say a magenta laidacation once.

Say a magenta ledacation once.

Say a magenta ludacation once.

Say a magenta deelacation once.

Say a magenta dilacation once.

Say a magenta dailacation once.

Say a magenta delacation once.

Say a magenta dulacation once.

A.3 Real Words in a Carrier Phrase

The subjects were instructed to read the following sentences from cards, emphasizing the word "again."

Say a magenta disobedience again.

Say a magenta lobbied again.

Say a magenta verbatim again.

Say a magenta exacerbated again.

Say a magenta abysmal again.

Say a magenta tidbit again.

Say a magenta alphabetical again.

Say a magenta alphabet again.

Say a magenta rebuttal again.

Say a magenta filibuster again.

Say a magenta indecently again.

Say a magenta candied again.

Say a magenta lackadaisical again.

Say a magenta accommodated <u>again</u>.

Say a magenta discipline <u>again</u>.

Say a magenta detriment <u>again</u>.

Say a magenta detrimental <u>again</u>.

Say a magenta industrial <u>again</u>.

Say a magenta industrialization <u>again</u>.

Say a magenta geezer <u>again</u>.

Say a magenta fogeys <u>again</u>.

Say a magenta gator <u>again</u>.

Say a magenta alligator <u>again</u>.

Say a magenta schizoid <u>again</u>.

Say a magenta schizophrenic <u>again</u>.

Say a magenta spaghetti <u>again</u>.

Say a magenta guttural <u>again</u>.

Say a magenta customarily <u>again</u>.

Say a magenta fatigue <u>again</u>.

Say a magenta signature <u>again</u>.

Say a magenta integrity <u>again</u>.

Say a magenta architecture <u>again</u>.

Say a magenta queasiness <u>again</u>.

Say a magenta bittersweet <u>again</u>.

Say a magenta dissuaded <u>again</u>.

Say a magenta antiquated <u>again</u>.

Say a magenta inquisitive <u>again</u>.

Say a magenta ventriloquism <u>again</u>.

Say a magenta question <u>again</u>.

Say a magenta questionnaire <u>again</u>.

Say a magenta Fuzzy Wuzzy <u>again</u>.

Say a magenta seaweed <u>again</u>.

Say a magenta jaywalking <u>again</u>.

Say a magenta unreasonable <u>again</u>.

Say a magenta decrease again.

Say a magenta radio again.

Say a magenta criticism again.

Say a magenta aristocratic again.

Say a magenta incredibly again.

Say a magenta preservation again.

Say a magenta frustrating again.

Say a magenta crustacean again.

Say a magenta obsolete again.

Say a magenta isosceles again.

Say a magenta complacent again.

Say a magenta accumulated again.

Say a magenta literature again.

Say a magenta litigation again.

Say a magenta athletic again.

Say a magenta illustrious again.

Say a magenta conceal again.

Say a magenta azalea again.

Say a magenta diligently again.

Say a magenta delta again.

Say a magenta celebration again.

Say a magenta adulterated again.

Say a magenta insult again.

Say a magenta legislators again.

Say a magenta population again.

Say a magenta statehouse again.

Say a magenta condition again.

Say a magenta protection again.

Say a magenta recite again.

A.4 Read Story

The subjects were instructed to read the following story as if reading a newspaper article to a same-age friend. The numbers appearing after some words in the following text indicate repetitions of words to be studied. (The subject's copy of the story did not include the numbers.) The subject was asked after every one or two paragraphs to retell what he or she had just read.

PARAGRAPH 1

For the past few years, we have lobbied(1) the legislature for a law promoting the preservation(1) of endangered crustaceans(1) in the delta(1). We find the recent decrease(1) in the crustacean(2) population(1) alarming. However, not everyone feels this way. We are opposed by the group which lobbies for the preservation(2) of the alligator(1) population(2). The alligators(2) are also endangered, because people hunt them in disobedience(1) of an existing law. Both populations live in the delta(2), which is a region shaped like an isosceles(1) triangle. The crustaceans(3) are prevalent on the eastern "leg" of the isosceles(2) triangle, and the gators(1) lived on the western "leg" until recently. The situation of the crustaceans(4) has been exacerbated(1) by the alligators(3), who have been moving into the eastern area and eating them. The gator(2) lobbyists believe that crustacean(5) protection(1) is necessarily a detriment(1) to the alligators(4). We find this stand unreasonable(1). The alligators(5) can find enough food without eating crustaceans(6). There are enough natural resources for both the alligator(6) and crustacean(7) populations(3) to be accommodated(1) in the delta(3).

PARAGRAPH 2

Most legislators(1) have no integrity(1) and a lackadaisical(1) attitude which we find frustrating(1). We call them the old fogeys(1) and the geezers(1). One legislator(2), an illustrious(1), aristocratic(1)-looking man with a guttural(1) voice, is an avid gator(3) supporter. We call him "Fuzzy Wuzzy(1)." He is a man of great integrity(2) and self-discipline(1), and he works diligently(1) at his job. However, he can be unreasonable(2). Though customarily(1) soft-spoken, the last time the crustacean(8) preservation(3) bill wasargued, he delivered a fiery rebuttal(1). He then led a filibuster(1) for five abysmal(1) hours, during which he read the phone book in alphabetical(1) order. We have explained that the crustacean(9) law would not be detrimental(1) to the alligators(7) or lead to a decrease(2) in the alligator(8) population(4). In fact, we should join forces against the industrial(1) lobbyists. Industrialization(1) is a threat to both the the gators(4) and the crustaceans(10). However, the gator(5) lobbyists are quite complacent(1) about their good relations with the industrial(2) lobbyists and don't conceal(1) it. They believe industrialization(2) is not detrimental(2) to their gators(6).

PARAGRAPH 3

The bill came up again this year. We lobbied(2) diligently(2) and handed out informational literature(1) and questionnaires(1). Our questions(1) to the public were straightforward: did they want to stop the extinction of the crustaceans(11), et cetera. The answers on the questionnaires(2) showed that much of the public, too, had a lackadaisical(2) attitude. However, we accumulated(1) some signatures(1) supporting our position. In spite of our abysmal(2) chances, we presented the questionnaire(3) and the signatures(2) to the legislators(3). The old fogeys(2) and the geezers(2) were not dissuaded(1) from their incredibly(1) lackadaisical(3) positions.

PARAGRAPH 4

The gator(7) lobbyists responded with their own questionnaire(4). Their questions(2) were misleading. An example question(3) was "Since the crustacean(12) preservation(4) bill would cause a decrease(3) in the alligator(9) population(5), do you oppose it?" We thought the questions(4) were an insult(1) to the public's intelligence, but their questionnaire(5) led many people to put their signatures(3) on their petition. The gator(8) lobbyists then presented the accumulated(2) signatures(4) to the old fogeys(3) and the geezers(3). They were very impressed by the large number of signatures(5).

PARAGRAPH 5

The testy relationship with our opposition was exacerbated(2) when they aired an indecently(1) flashy radio(1) commercial. Fuzzy Wuzzy's(2) rebuttal(2) and the filibuster(2) were glorified. Their criticism(1) of us was unfair and unreasonable(3). Incredibly(2) sensationalistic tidbits(1) were thrown in. But that wasn't all. In their mailed literature(2), they even accused us of disobedience(2) of the law because we handed out our literature(3) directly to people on the street. We are considering litigation(1) to counter this assault on our integrity(3).

PARAGRAPH 6

As the day approached when our bill was to be argued, we had a strategy meeting. Five of us, John, Carla, Marge, Jack, and Lucy, met over a spaghetti(1) dinner. Marge said: "How can we prevent our aristocratic(2) friend, the illustrious(2) Fuzzy Wuzzy(3) from leading another unreasonable(4) filibuster(3)? I can't bear hearing the phone book recited(1) in alphabetical(2) order by that guttural(2) voice again. It's an insult(2) to my ears. I never thought the alphabet(1) could be so painful." Just then, John came out with a bowl of alphabet(2) soup, our first course.

"Alphabet(3) soup, very funny," we said.

Marge said, " If only the public would be more inquisitive(1). They could find out for themselves that the gator(9) lobbyists' criticism(2) is false and unreasonable(5), and that we did nothing in disobedience(3) of the law."

John served the spaghetti(2) to everyone. Lucy brought out some wine coolers, which Jack disdainfully described as adulterated(1) swill. He claimed that just the smell caused queasiness(1) for him. Lucy exercised considerable self-discipline(2) in not slapping him.

" How can we make people inquisitive(2)? We've tried to change their lackadaisical(4) attitude, and it's been frustrating(2). If they're not inquisitive(3), then they're just not," said Lucy, laying letters of the alphabet(4) from her soup onto the spaghetti(3) on her plate.

"Well, inquisitive(4) or not inquisitive(5), the public has to know that they lied, and litigation(2) is the only way to achieve that. We can't allow our integrity(4) to be questioned(5)," said Carla, stabbing Marge's spaghetti(4) with a fork.

"Would litigation(3) be detrimental(3) to our image? Usually, the public is suspicious of lawsuits," said Jack, sipping his adulterated(2) swill.

"Any detriment(2) from pursuing litigation(4) will be offset when we win," said Carla.

After we finished the spaghetti(5) dinner, Marge brought out her dessert of candied(1) fruits. These candied(2) fruits had a bittersweet(1) taste.

"So we've decided to pursue litigation(5), right?" said Lucy, eyeing the bittersweet(2) tidbit(2) in her hand, unable to conceal(2) her doubts about eating it.

PARAGRAPH 7

The day for the vote came up, and we went to the statehouse(1). We had lobbied(3) for months and had planned a rally for the last day. The more athletic(1) participants organized a road race from the delta(4) to downtown to publicize our case. The less athletic(2) participants were accommodated(2) in the gallery. Others accumulated(3) before the statehouse(2) with signs and informational literature(4). The contingents kept in contact through some obsolete(1) and antiquated(1) two-way radios(2). The gator(10) lobbyists also had a demonstration. They formed two lines in the shape of an isosceles(3) triangle, representing the delta(5). A crowd of people accumulated(4) to watch. Suddenly, a scantily, almost indecently(2) clad young man sprang from behind the azalea(1) bushes in front of the statehouse(3). He had an alligator(10) mask on to conceal(3) his face and strands of seaweed(1) hanging from his body. Quite athletic(3), he did some cartwheels through the isosceles(4) triangle formation, seaweed(2) flying, then ran behind the azaleas(2) again.

PARAGRAPH 8

Then, the people forming the isosceles(5) triangle representing the delta(6) started a "wave," and he sprang from his position among the azaleas(3) again. We thought that such an indecently(3) showy display would be detrimental(4) to the gator(11) lobbyists, but most of the onlookers couldn't conceal(4) their glee. Many even picked up the strands of seaweed(3) and azalea(4) blossoms that the athletic(4) young man had caused to fall to the ground and waved them. It was quite a sight in front of the antiquated(2) statehouse(4), whose architecture(1), though obsolete(2) in its functionality, has a certain aristocratic(3) dignity. The young man was completing his third pass behind the azalea(5) bushes when our athletic(5) contingent arrived as announced via radio(3). By this time, the young man was showing signs of fatigue(1) and queasiness(2) from the cartwheels. No wonder he was suffering from fatigue(2) and queasiness(3), after a performance like that.

PARAGRAPH 9

Our speaker then addressed the onlookers. The aristocratic(4) architecture(2) of the statehouse(5) was a suitable backdrop for her calm and collected speech. She wanted the onlookers to be dissuaded(2) from accepting a complacent(2), lackadaisical(5) attitude. In her criticism(3) of the gator(12) lobbyists, she couldn't muster the self-discipline(3) to conceal(5) her disgust at the indecently(4) showy display, frowning at the piles of seaweed(4) which had accumulated(5) by the podium. Her haughty disapproval of our opponents' popular display may have been a detriment(3) to our image. However, she went on to point out that the industrial(3) lobbyists were our real opponents, since industrialization(3) would lead to a decrease(4) in both the alligator(11) and crustacean(13) populations(6). Onlookers were still waving strands of seaweed(5) in the air. Unfortunately, the industrial(4) lobbyists had lobbied(4) extensively and distributed literature(5) to the public themselves. Industrialization(4) would lead to a decrease(5) in the unemployment rate, they said. Indeed, the public seemed to believe that industrial(5) concerns and industrialization(5) were in their best interests.

PARAGRAPH 10

Then we went into the legislative chamber to hear the bill being argued. The illustrious(3) Fuzzy Wuzzy(4) was there, along with the customarily(2) complacent(3) old fogeys(4) and geezers(4). The speech for the bill was incredibly(3) abysmal(3). The legislator(4) argued that lack of concern for crustaceans(14) was an antiquated(3) and obsolete(3) attitude, much like jaywalking(1). In the past, jaywalking(2) was customarily(3) considered "cool," he said, but nowadays people are easily dissuaded(3) from jaywalking(3). It's also modern to be concerned about detriments(4) to crustaceans(15), and those who don't want to have antiquated(4) and obsolete(4) views should be easily dissuaded(4) from their stand against the bill. We didn't see the connection between jaywalking(4) and crustaceans(16). In fact, it was an insult(3) that he thought crustacean(17) extinction was no more serious than jaywalking(5).

PARAGRAPH 11

When the rebuttal(3) time started, we had a surprise. The illustrious(4) Fuzzy Wuzzy(5) had recruited another legislator(5). She stood up and recited(2) Fuzzy Wuzzy's(6) old speech verbatim(1), using a similar guttural(3) voice. It was like a bizarre ventriloquism(1) act. As the rebuttal(4) proceeded, this legislator(6) threatened with a filibuster(4), during which she would read the phone book in alphabetical(3) order, just as Fuzzy Wuzzy(7) had done. It was frustrating(3) for us, but reciting(3) rebuttals(5) verbatim(2) in a guttural(4) voice and even ventriloquism(2) acts were not in disobedience(4) of any law. In fact, if we had called out, we would have been acting in disobedience(5) of the rules, which would draw criticism(4) and be detrimental(5) to our image. Exercising great self-discipline(4), we recited(4) the alphabet(5) to ourselves to calm down. Suddenly, the ventriloquism(3) act stopped, and the legislator(7) said some positive things about us. Her voice even seemed less guttural(5). Then the ventriloquism(4) act resumed. She recited(5) more of Fuzzy Wuzzy's(8) speech verbatim(3), threatening with the filibuster(5) and reading the phone book in alphabetical(4) order, the whole bit. After a few minutes, this ventriloquism(5) act again stopped.

PARAGRAPH 12

The legislator(8) seemed to be schizophrenic(1). We started calling her Schizoid(1) Sue. It was frustrating(4) watching Schizoid(2) Sue's schizophrenic(2) ways, alternately talking about reading phone books in alphabetical(5) order and the need to preserve crustaceans(18). Gradually, Schizoid(3) Sue became less schizophrenic(3) and spent less time reciting(6) Fuzzy Wuzzy's(9) speech verbatim(4). She gradually decreased her criticism(5) of the crustacean(19) preservation(5) bill. We thought that simple fatigue(3) was the cause. However, she turned to diligently(3) exploring the relationship among the industrialists, gator(13) lobbyists, and crustacean(20) lobbyists. Schizoid(4) Sue wasn't schizophrenic(4) at all. In fact, far from being schizophrenic(5), she presented a unified exposition of the relationships of the parties involved and dissuaded(5) many other legislators(9) from their customarily(4) complacent(4) stands.

PARAGRAPH 13

Fuzzy Wuzzy's(10) illustrious(5), aristocratic(5) face seemed quite pale. The customarily(5) complacent(5) old fogeys(5) and geezers(5), who had almost gone to sleep as Schizoid(5) Sue was reciting(7) Fuzzy Wuzzy's(11) speech verbatim(5), were now showing interest. The vote was overwhelming to pass the crustacean(21) preservation(6) bill. The gator(14) lobbyists found the vote very frustrating(5), almost an insult(4) to themselves personally. We felt sympathy for the gator(15) supporters, since many of them were people of great integrity(5) who had lobbied(5) diligently(4). Of course, others in their ranks had organized the indecently(5) showy display we saw earlier. We tried to persuade them that our bill would be no detriment(5) to them, that no insult(5) was intended, and that our rivalry was the true antiquated(5) and obsolete(5) idea. Their abysmal(4) mood only seemed to be exacerbated(3) by this. We, however, were incredibly(4) happy that lobbying diligently(5) had paid off for us. A celebration(1) was definitely in order.

PARAGRAPH 14

The celebration(2) took place that evening at Marge's apartment. Only ten guests could be accommodated(3) in the small apartment, but thirty came. The crowded condition(1) was exacerbated(4) by the hot, humid weather. For all the guests to be accommodated(4), the party had to spread out into the back courtyard. The refreshments at the celebration(3) included the bittersweet(3) candied(3) tidbits(3) of fruit which were Marge's specialty and a huge multi-tiered cake of impressive architecture(3). Lucy brought some more of the so- called adulterated(3) swill. We ate the bittersweet(4) candied(4) tidbits(4) while admiring the incredibly(5) elaborate architecture(4) of the cake. We listened to the radio(4) newscasters' account of the day's events. However, in spite of the happy mood at the celebration(4), fatigue(4) got the best of some of us, and the so-called adulterated(4) swill caused queasiness(4) to come on. Our condition(2) was exacerbated(5) by the crowd which could not be accommodated(5) in the small apartment and the radio(5) blaring in the background. Soon, our condition(3) became abysmal(5) and the thought of bittersweet(5) candied(5) tidbits(5) of fruit, cakes no matter how impressive the architecture(5), and adulterated(5) wine made us sick. We didn't want to spoil the celebration(5), but the queasiness(5) and fatigue(5) was about to overpower us. With great self-discipline (5), we said good-bye cheerily and went home to sleep.

A.5 Retold Story

Subjects were asked after reading every one or two paragraphs of the story to retell the story. They were allowed to refer to the written text if they could not remember. Occasionally, the experimenter would ask a question. An example of a transcript of part of the retold story is shown below.

Subject: OK, um, it's the day of the legislators going to vote on the, uh, the bill that they're, that these environmentalists have lobbied for and, um, they're planning a rally, uh, and some of the, well, the more athletic people have organized a road race from, uh, the delta down to the, uh, statehouse, and um, the less athletic people were just, uh, kind of giving out information and, um, some literature about the, the bill that's being presented. Um, the gator lobbyists also had a demonstration, um, they formed an isosceles triangle, and, um, after, well, one, a, uh, a young man who was, like, a young indecently (laugh) uh, clad young man sprang from behind the bushes and, um, appeared to, uh, well, he was, he was scantily clad with, uh, seaweed all on his body and he had on an alligator mask to conceal his face, um, and he did some acrobatic, you know, cartwheels, uh, through this isosceles triangle, um, after that, well, the, the people, the gator lobbyists, um, started a wave within this isosceles triangle, um, and the environmentalists felt that this would, uh, would be, d-, uh, make the gator lobbyists look bad, um, (sigh) ... Finally, after, uh, after all of this was going on, the, um, when the running, the running race had, was just finishing, as it was announced over the radio, um, by the, by that time this young man who had been doing all these cartwheels was pretty exhausted, so it was about, about time for the main event of the speaker. Um, OK, uh ... The speaker(s) was some, apparently some, uh, environmentalist who they had invited. Uh, they didn't really go into much detail about that. Um, let's see, uh, she, oh well, when she was talking about the, uh, as she, uh, was talking to the gator lobbyists, she couldn't , uh, notice but, you know, to feel some, uh, disappointment at the, uh, indecently showy display of the, uh, of this, um, seaweed which had, which was by the podium. Um, this might have been detrimental to the environmentalists' image, um, but, uh, she went on to, uh, say that, um, the, uh, industrialists were, the people who we're really after, and, um, since industrializa-, the industrialists, um, would, uh, or the industrialization would-, would be, uh, bad for the alligator and crustacean populations, um, uh, OK ...

Experimenter: OK, tell me about the, um, let's see, what happened when they went into the legislative chamber, the speeches that were given.

Subject: OK, um, so they went into the, uh, chamber, and, uh, Fuzzy Wuzzy was there and all the other legislators, the old fogeys and geezers as they customarily call them ... Um, the, the bill was i-, incredibly, uh, well, the speech for the bill was incredibly boring. Uh, the, um, the legislator ar-, argued that, uh, this, um, the lack of concern was, uh, for crustaceans like, uh, jaywalking, which was, the environmentalists were, felt, you know, it's, what a joke, you know? I mean, this is, this guy is like, uh, you know ... They didn't, they didn't understand how jaywalking could have any connection with crustaceans, and they felt it was an insult, and, uh, they ... That's about it.

Appendix B

Additional F1-F2 Plots and Tables

This appendix shows F1-F2 plots for speakers RU, EE, and MP. All plots were made in the same way as the JS plots shown in Chapter 3, except for the separate plots showing spontaneous speech. Since only one repetition of each spontaneous word was labelled for RU, EE, and MP, carrier phrase words could also be matched to the spontaneous words. Therefore, all three speech styles are shown.

Table B.1: Number of tokens for each F1-F2 plot for speakers RU, EE, and MP.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	12	12	12	12	10
	sec.	12	12	12	12	10
context	b-init.	4	4	4	4	4
	d-init.	4	4	4	4	4
	g-init.	4	4	4	0	4
	g-fin.	0	0	0	4	0
	w-init.	4	4	4	4	0
	r-init.	4	4	4	4	4
	l-init.	4	4	4	0	0
	l-fin.	0	0	0	4	4
style	nons.	0	0	0	0	0
	car.ph.	15	14	14	14	12
	read	15	14	14	14	12
RU style	car.ph.	11	12	17	13	10
	read	11	12	17	13	10
(read-sp.)	spont.	11	12	17	13	10
EE style	car.ph.	11	14	18	14	9
	read	11	14	18	14	9
(read-sp.)	spont.	11	14	18	14	9
MP style	car.ph.	5	10	15	9	8
	read	5	10	15	9	8
(read-sp.)	spont.	5	10	15	9	8

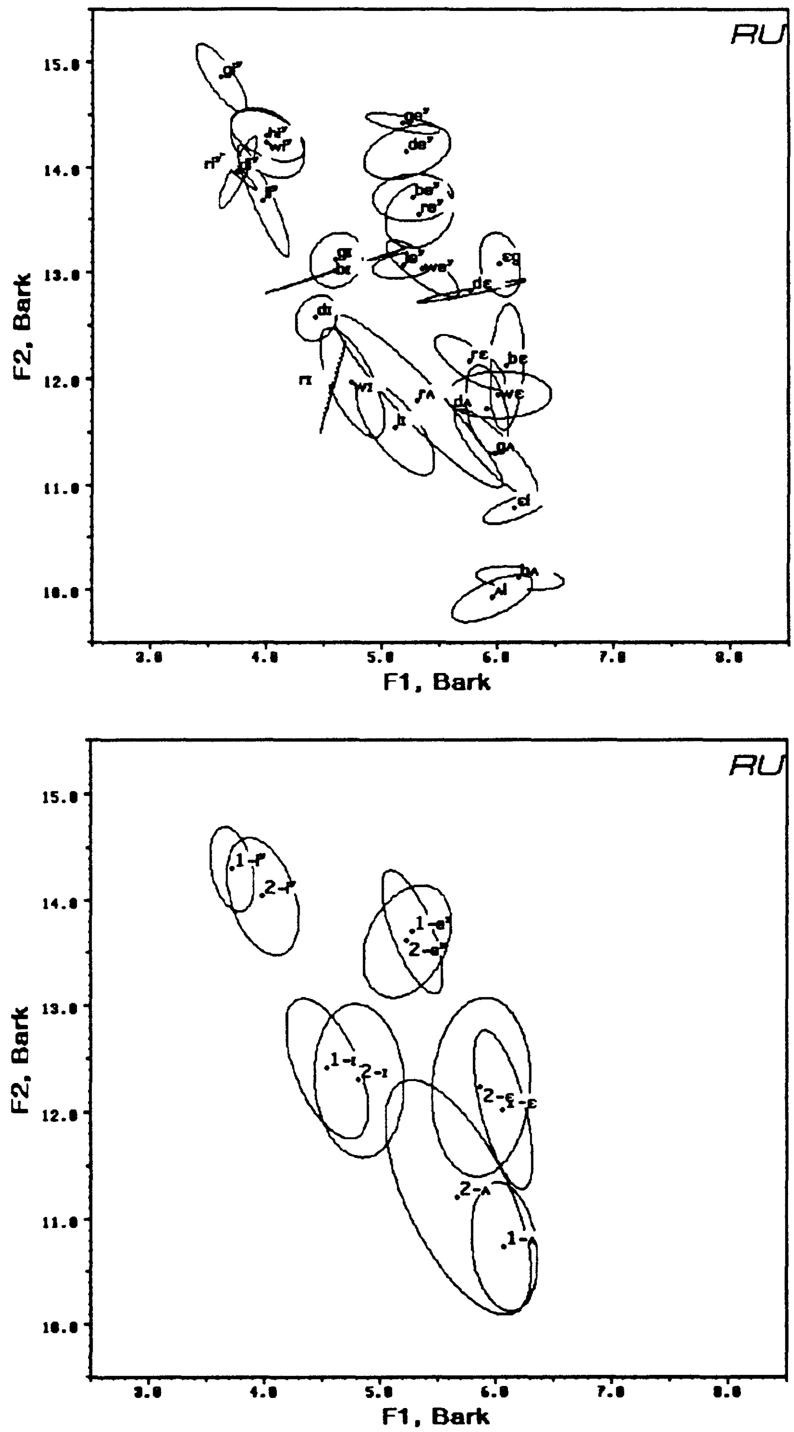


Figure B.1: RU's vowels grouped according to context (top) or stress (bottom).

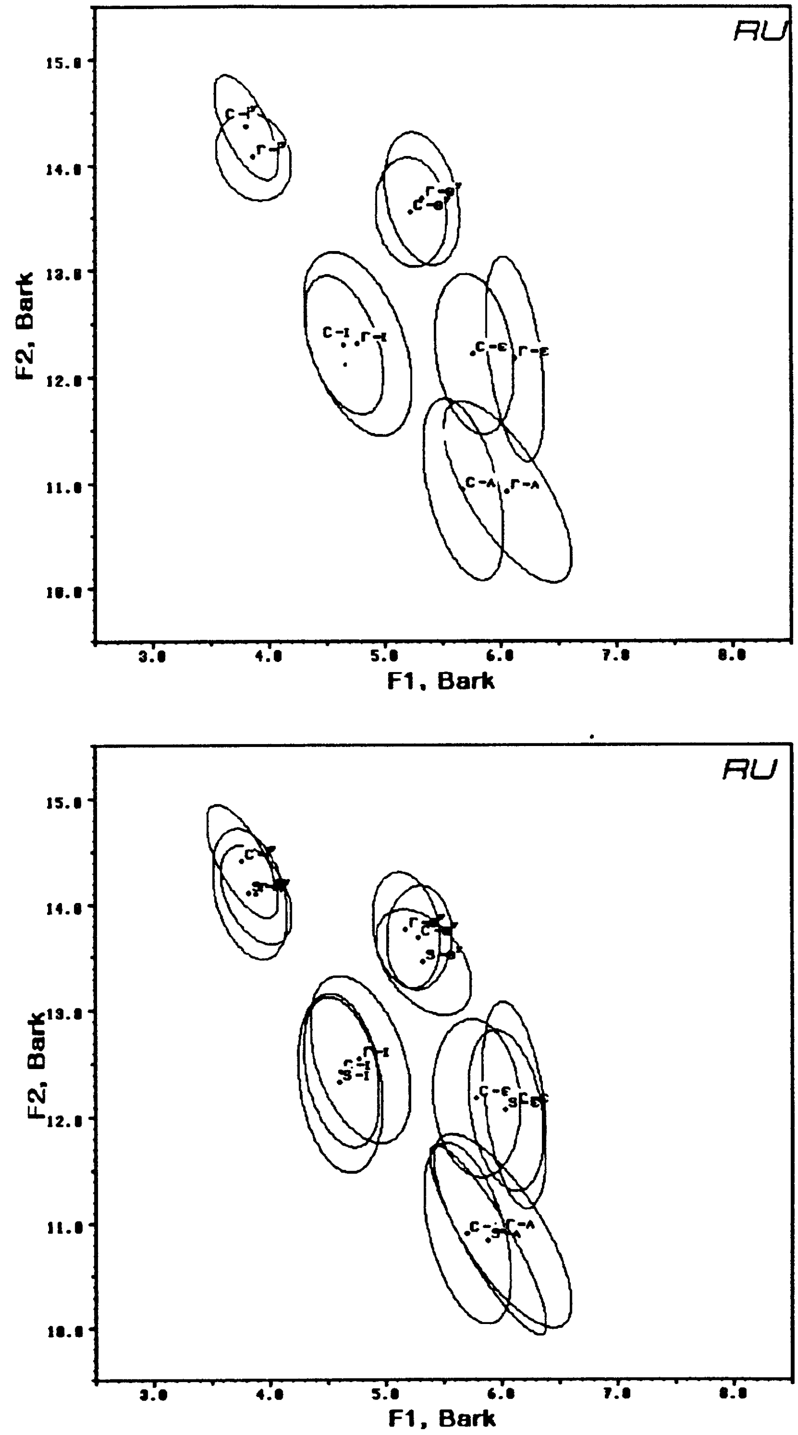


Figure B.2: RU's vowels grouped according to style, carrier-phrase and read-story (top) or carrier-phrase, read-story, and spontaneous (bottom).

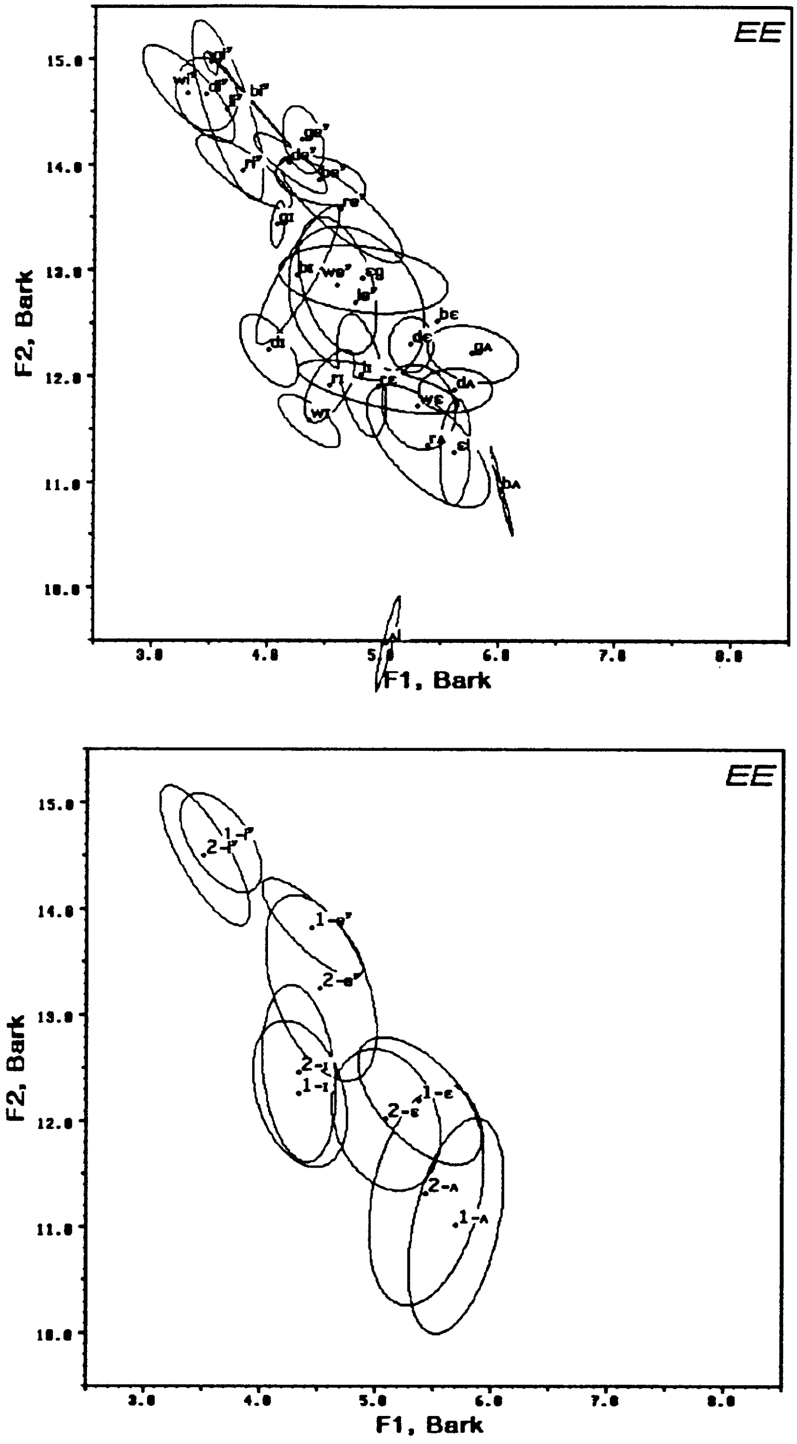


Figure B.3: EE's vowels grouped according to context (top) or stress (bottom).

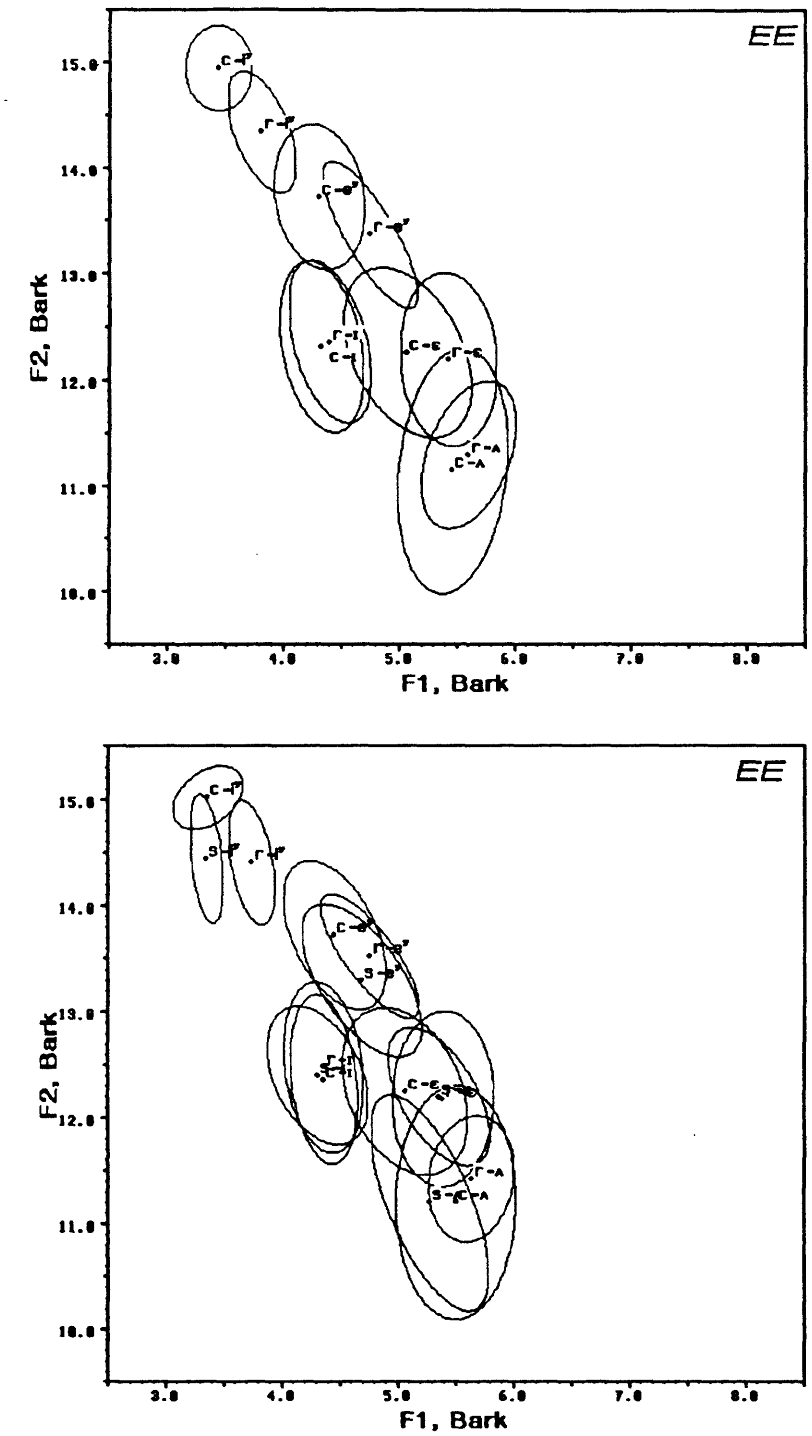


Figure B.4: EE's vowels grouped according to style, carrier-phrase and read-story (top) or carrier-phrase, read-story, and spontaneous (bottom).

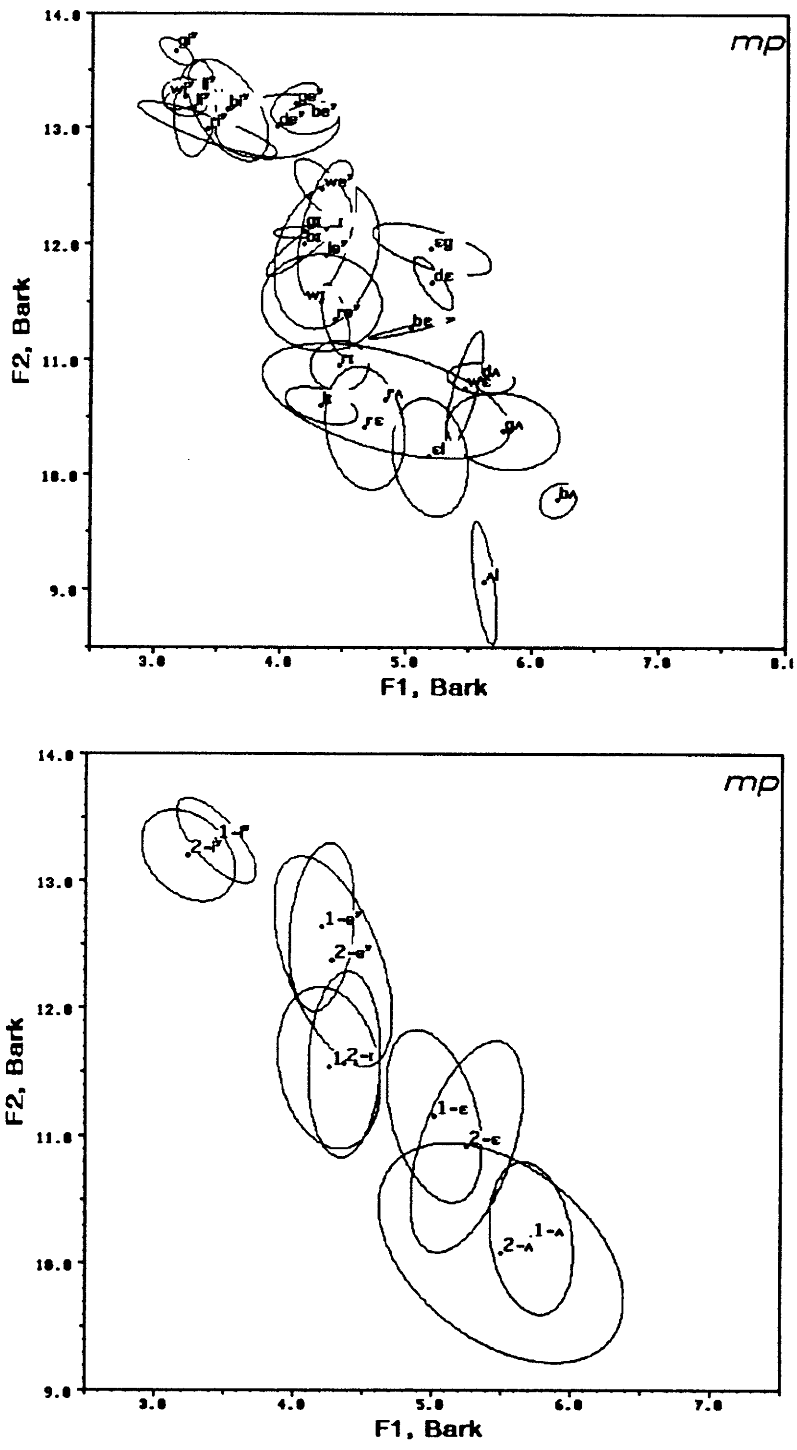
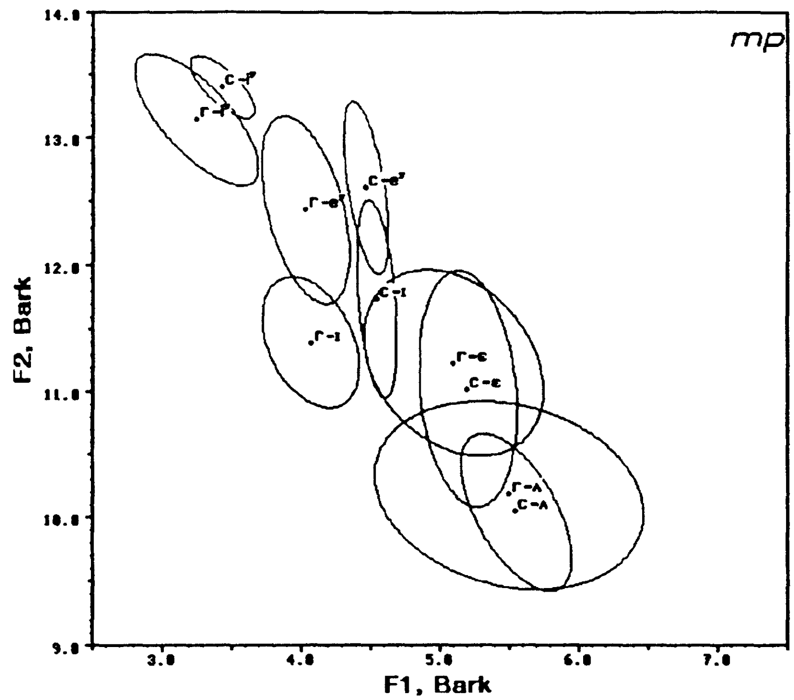


Figure B.5: MP's vowels grouped according to context (top) or stress (bottom).



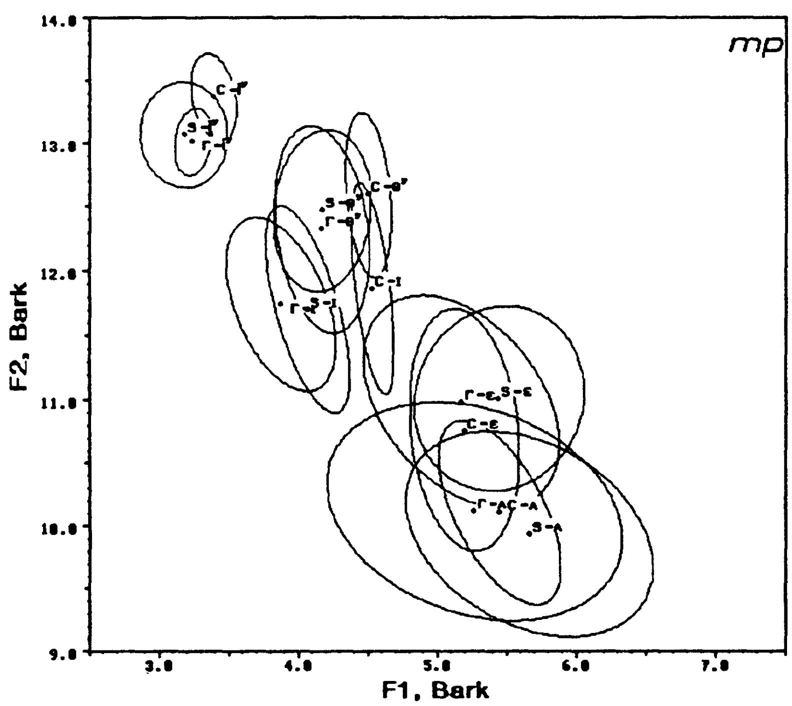


Figure B.6: MP's vowels grouped according to style, carrier-phrase and read-story (top) or carrier-phrase, read-story, and spontaneous (bottom).

Appendix C

Formant, Fundamental Frequency, and Duration Data

The following is a list of raw data for the four speakers. For each formant, the quarter-point, midpoint, and three-quarter-point were listed, in that order. For the present study, Hertz values were converted to Bark values using the approximation derived by Schroeder et al. (1979):

$$B = 7\ln\left(\frac{f}{650} + \sqrt{\left(\frac{f}{650}\right)^2 + 1}\right)$$

The duration and median F0 values are also given for each vowel. The F0 values were not hand-corrected, but values outside a reasonable range (120-280 Hz fro females, 50-220 Hz for males) were not included in the determination of the median. The F0 track was computed with the *Spire* implementation of the Gold-Rabiner pitch tracker. The data are divided first by speaker, then by speech style, then listed alphabetically by the word from which the vowel was taken. The label identifies the token uniquely, as explained in Figure C.1.

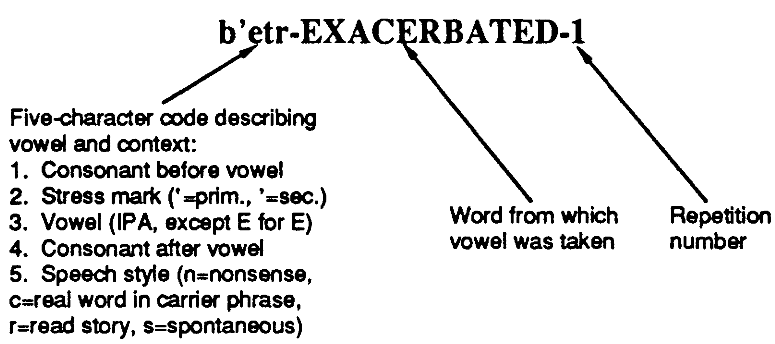


Figure C.1: Description of labels for vowel data.

C.1 Speaker JS (Male)

Label	F1 (Hz)	F2 (Hz)	F3 (Hz)	Du. (ms)	F0 (Hz)
b'edn-BAID-1	344 344 344	2000 2047 2047	2703 2766 2719	137.3	120
b'edn-BAID-2	375 391 406	2000 2031 2062	2625 2672 2672	131.9	117
b'Edn-BED-1	469 516 469	1703 1766 1750	2625 2656 2703	110.0	114
b'Edn-BED-2	469 453 422	1766 1766 1703	2563 2609 2703	110.6	118
b'idn-BEED-1	266 281 312	2078 2094 2109	2766 2922 2797	108.8	125
b'idn-BEED-2	281 281 297	2109 2156 2156	2891 3016 2828	121.0	120
b'Idn-BID-1	375 391 375	1844 1859 1781	2719 2797 2781	89.2	119
b'Idn-BID-2	391 422 422	1844 1844 1812	2672 2703 2672	86.9	114
b'Λdn-BUD-1	562 578 594	1266 1312 1438	2453 2578 2672	110.0	117
b'Λdn-BUD-2	562 609 578	1203 1297 1406	2422 2563 2672	127.5	119
d'edn-DAID-1	391 391 359	1984 2016 2062	2797 2781 2734	131.5	114
d'edn-DAID-2	391 422 422	2016 1984 2000	2875 2797 2766	121.2	111
d'egn-DAIG-1	422 422 328	1891 1969 2047	2781 2734 2703	125.6	112
d'egn-DAIG-2	438 453 375	1891 1891 2031	2781 2734 2641	154.7	127
d'eln-DAIL-1	391 438 469	2031 2000 1703	2875 2750 2656	154.3	114
d'eln-DAIL-2	391 438 453	2016 1969 1656	2813 2719 2672	148.5	113
d'ewn-DAYW-1	359 359 359	2062 2109 2062	2844 2891 2641	116.9	121
d'ewn-DAYW-2	359 359 375	2031 2062 1984	2750 2719 2563	144.2	116
d'Edn-DED-1	422 453 438	1844 1812 1766	2813 2766 2734	96.9	117
d'Edn-DED-2	422 453 453	1844 1797 1766	2781 2750 2719	97.8	113
d'idn-DEED-1	312 297 281	2109 2172 2187	2922 2984 2922	128.4	115
d'idn-DEED-2	266 266 266	2187 2172 2172	2971 2914 2844	107.5	126
d'ign-DEEG-1	266 266 250	2047 2094 2141	2922 2969 3063	95.6	124
d'ign-DEEG-2	266 266 266	2031 2094 2109	2859 2750 2703	105.0	127
d'iln-DEEL-1	250 297 344	2109 2109 1953	3031 2828 2641	112.4	119
d'iln-DEEL-2	266 312 359	2094 2031 1875	2875 2688 2594	108.5	125
d'iwn-DEEW-1	266 250 266	2031 2094 2047	2952 2914 2448	102.0	112
d'iwn-DEEW-2	281 266 281	2062 2094 2125	2953 2859 2609	108.1	125
d'Egn-DEG-1	453 438 344	1875 1937 2062	2750 2672 2656	112.5	115
d'Egn-DEG-2	453 438 359	1828 1922 2031	2766 2688 2609	122.2	120
d'Eln-DEL-1	484 562 594	1812 1609 1375	2781 2750 2750	103.0	113
d'Eln-DEL-2	453 547 516	1844 1703 1438	2766 2766 2750	89.0	117
d'Idn-DID-1	328 328 312	1906 1922 1875	2766 2734 2750	76.4	116
d'Idn-DID-2	344 359 359	1953 1937 1891	2813 2766 2734	90.2	126
d'Ign-DIG-1	359 344 328	1891 1984 2078	2859 2828 2743	95.0	128
d'Ign-DIG-2	344 344 312	1953 2031 2062	2750 2719 2657	86.0	127
d'Iln-DIL-1	422 453 438	1719 1562 1344	2750 2703 2672	81.6	116
d'Iln-DIL-2	375 438 422	1750 1484 1281	2703 2672 2688	82.4	118
d'Λdn-DUD-1	531 547 547	1687 1609 1562	2672 2641 2641	101.8	113
d'Λdn-DUD-2	500 562 500	1672 1594 1562	2734 2703 2719	93.0	117
d'Λgn-DUG-1	484 484 422	1656 1641 1797	2641 2531 2238	115.9	119
d'Λgn-DUG-2	531 516 406	1609 1672 1844	2656 2547 2406	110.1	114
d'Λln-DUL-1	516 594 609	1578 1406 1266	2750 2734 2766	94.5	105
d'Λln-DUL-2	500 562 547	1609 1391 1203	2672 2641 2719	104.6	109
g'edn-GAID-1	297 344 359	2109 2125 2094	2844 2766 2688	123.3	121
g'edn-GAID-2	344 406 422	2125 2094 2062	2781 2594 2625	144.6	114
g'Edn-GED-1	438 500 531	2047 1891 1797	2781 2688 2672	101.0	112
g'Edn-GED-2	438 469 453	1984 1906 1844	2844 2703 2688	94.6	117
g'idn-GEED-1	250 266 297	2125 2141 2109	3305 3203 2891	113.7	119
g'idn-GEED-2	266 281 297	2172 2187 2187	3276 3371 3125	91.2	117

g'Idn-GID-1	312 344 328	2062 2016 1937	2848 2766 2703	69.0	115
g'Idn-GID-2	281 406 406	2078 2000 1937	3038 2781 2703	91.0	136
g'Λdn-GUD-1	500 547 531	1812 1609 1531	2406 2547 2594	81.7	107
g'Λdn-GUD-2	516 562 547	1625 1500 1516	2457 2533 2656	110.9	114
l'edn-LAID-1	438 422 406	1906 2000 1984	2719 2734 2688	110.9	115
l'edn-LAID-2	469 422 422	1906 2000 2047	2656 2703 2672	114.9	109
l'Edn-LED-1	531 547 547	1547 1656 1641	2703 2703 2703	98.6	111
l'Edn-LED-2	500 531 516	1547 1578 1578	2750 2719 2734	103.5	110
l'idn-LEED-1	281 266 297	2047 2125 2078	2641 2734 2703	122.5	117
l'idn-LEED-2	266 266 281	2016 2078 2047	2672 2797 2781	105.1	117
l'Idn-LID-1	422 422 438	1687 1719 1703	2641 2672 2672	80.4	116
l'Idn-LID-2	359 359 375	1516 1578 1609	2594 2594 2609	88.3	129
l'Λdn-LUD-1	547 609 562	1250 1281 1391	3000 2984 2875	97.9	115
l'Λdn-LUD-2	547 562 531	1234 1328 1406	2906 2828 2750	89.5	113
r'edn-RAID-1	422 406 391	1891 1984 1984	2171 2324 2505	106.5	117
r'edn-RAID-2	406 422 438	1875 1969 2000	2266 2344 2469	97.3	125
r'Edn-RED-1	438 484 469	1562 1656 1703	2156 2531 2625	113.2	111
r'Edn-RED-2	500 500 453	1594 1734 1719	2210 2609 2656	98.4	114
r'idn-REED-1	266 281 297	2062 2078 2078	2371 2703 2828	79.6	107
r'idn-REED-2	297 297 312	1953 2016 2062	2495 2656 2734	106.7	114
r'Idn-RID-1	359 391 406	1547 1656 1719	1953 2156 2391	89.4	119
r'Idn-RID-2	422 422 359	1594 1672 1656	2047 2234 2484	68.3	114
r'Λdn-RUD-1	547 562 578	1406 1422 1406	2203 2453 2594	104.0	111
r'Λdn-RUD-2	516 562 505	1359 1375 1406	2500 2531 2531	94.8	116
w'edn-WAID-1	422 422 391	1484 1875 2000	2125 2297 2531	115.3	116
w'edn-WAID-2	422 438 422	1234 1844 1969	2109 2219 2578	125.4	114
w'Edn-WED-1	469 500 500	1391 1562 1656	2297 2438 2563	85.0	119
w'Edn-WED-2	484 547 531	1234 1453 1531	2141 2266 2343	97.8	113
w'idn-WEED-1	266 266 281	1657 2152 2141	2210 2381 2703	100.3	115
w'idn-WEED-2	281 281 281	1719 2156 2141	2190 2448 2688	99.9	121
w'Idn-WID-1	344 359 359	1312 1516 1656	2094 2125 2156	78.0	115
w'Idn-WID-2	391 391 359	1281 1547 1687	2187 2219 2281	74.9	115
w'Λdn-WUD-1	516 562 594	922 1188 1344	2375 2453 2484	85.0	106
w'Λdn-WUD-2	531 562 562	891 1125 1266	2312 2391 2467	78.1	115
b'edn-BAID-1	422 406 422	2031 2125 2141	2641 2734 2734	145.1	152
b'edn-BAID-2	406 406 422	1781 1812 1859	2516 2563 2641	110.9	109
b'Edn-BED-1	547 578 547	1766 1781 1766	2672 2781 2813	92.1	122
b'Edn-BED-2	500 547 500	1734 1766 1750	2688 2703 2719	116.1	112
b'idn-BEED-1	281 281 297	2109 2219 2172	2667 2762 2762	106.5	140
b'idn-BEED-2	266 250 266	2031 2078 2062	2914 3019 2962	108.7	119
b'Idn-BID-1	359 344 375	1906 1937 1906	2688 2688 2719	87.1	126
b'Idn-BID-2	391 375 344	1797 1750 1734	2578 2609 2625	54.1	124
b'Λdn-BUD-1	547 594 562	1281 1391 1484	2594 2672 2800	89.4	145
b'Λdn-BUD-2	562 594 578	1234 1312 1344	2438 2594 2609	79.2	111
d'edn-DAID-1	391 359 359	2000 2062 2109	2734 2750 2719	125.5	121
d'edn-DAID-2	422 438 422	1906 2016 2016	2828 2766 2750	116.9	116
d'egn-DAIG-1	438 391 328	1937 1984 2031	2828 2819 2733	113.7	117
d'egn-DAIG-2	406 422 312	1906 1937 2047	2797 2766 2734	123.2	113
d'eln-DAIL-1	406 422 484	1969 1984 1812	2688 2625 2578	133.5	119
d'eln-DAIL-2	406 438 484	2016 1937 1703	2781 2703 2656	133.5	113
d'ewn-DAYW-1	391 375 391	2062 2125 1984	2781 2703 2453	159.8	126
d'ewn-DAYW-2	359 375 406	1984 2016 1859	2781 2719 2297	153.0	116
d'Edn-DED-1	438 484 484	1875 1844 1859	2766 2750 2719	90.7	124
d'Edn-DED-2	422 484 516	1781 1781 1734	2750 2719 2672	97.3	106

d'idn-DEED-1	250	250	266	2125	2219	2172	3181	3200	3105	110.0	118
d'idn-DEED-2	281	281	297	2125	2172	2141	3086	2962	2867	117.8	119
d'ign-DEEG-1	281	281	281	2125	2187	2234	3047	3076	3086	85.8	139
d'ign-DEEG-2	297	297	281	2016	2094	2187	2781	2828	2886	89.5	148
d'iln-DEEL-1	266	281	359	2187	2156	1953	3078	2734	2594	121.3	124
d'iln-DEEL-2	297	359	422	2000	1984	1797	2766	2672	2594	96.7	109
d'iwn-DEEW-1	250	250	281	2125	2156	1953	3125	3038	2390	132.3	119
d'iwn-DEEW-2	266	266	281	2156	2281	2141	2971	2867	2531	111.7	125
d'Egn-DEG-1	453	453	391	1781	1812	2016	2703	2609	2524	107.0	116
d'Egn-DEG-2	438	422	312	1812	1922	2047	2797	2750	2656	101.4	116
d'Eln-DEL-1	469	578	578	1828	1594	1375	2703	2688	2703	107.3	117
d'Eln-DEL-2	469	547	578	1734	1547	1328	2703	2703	2719	100.4	104
d'Idn-DID-1	328	359	344	1906	1891	1859	2734	2719	2688	71.2	126
d'Idn-DID-2	328	359	359	1844	1844	1844	2844	2781	2750	74.4	124
d'Ign-DIG-1	297	297	297	2031	2094	2109	2766	2734	2641	73.1	138
d'Ign-DIG-2	344	312	297	1844	1937	1984	2781	2797	2703	80.9	119
d'Iln-DIL-1	375	469	453	1812	1656	1312	2750	2672	2719	89.3	119
d'Iln-DIL-2	406	453	438	1766	1609	1391	2781	2719	2703	91.9	114
d'Λdn-DUD-1	516	562	547	1687	1594	1531	2734	2688	2734	90.4	114
d'Λdn-DUD-2	469	547	505	1656	1578	1500	2813	2766	2719	93.8	116
d'Λgn-DUG-1	547	531	422	1594	1625	1828	2563	2328	2229	129.5	118
d'Λgn-DUG-2	484	438	422	1625	1641	1812	2734	2625	2594	113.7	118
d'Λln-DUL-1	531	594	578	1562	1344	1203	2762	2828	3000	79.2	123
d'Λln-DUL-2	484	531	531	1609	1438	1328	2719	2688	2734	88.8	111
g'edn-GAID-1	328	359	375	2172	2187	2156	2714	2724	2688	131.6	130
g'edn-GAID-2	297	344	375	2125	2125	2109	3141	2875	2734	125.0	120
g'Edn-GED-1	453	469	484	1937	1875	1812	2695	2656	2625	92.9	117
g'Edn-GED-2	375	500	500	2000	1937	1844	2797	2672	2688	102.5	113
g'idn-GEED-1	266	266	297	2203	2234	2156	3371	3124	2781	107.0	129
g'idn-GEED-2	250	266	281	2078	2062	2047	2838	2848	2766	91.9	120
g'Idn-GID-1	297	391	406	2047	2016	1984	2838	2703	2641	65.7	137
g'Idn-GID-2	344	375	391	2016	1969	1984	2859	2766	2734	75.6	119
g'Λdn-GUD-1	516	609	578	1797	1656	1578	2531	2578	2656	76.9	132
g'Λdn-GUD-2	469	531	500	1719	1641	1594	2469	2578	2594	83.8	119
l'edn-LAID-1	453	406	375	1891	2000	2031	2688	2734	2703	118.1	122
l'edn-LAID-2	457	422	406	1734	1875	1922	2672	2688	2672	122.4	99
l'Edn-LED-1	484	516	531	1516	1578	1609	2766	2797	2781	97.8	99
l'Edn-LED-2	641	656	656	1500	1547	1609	2828	2813	2781	95.5	111
l'idn-LEED-1	297	297	312	2062	2125	2125	2667	2734	2703	117.0	136
l'idn-LEED-2	312	297	297	2031	2125	2109	2594	2688	2641	91.0	116
l'Idn-LID-1	453	453	453	1531	1625	1609	2625	2641	2656	82.7	119
l'Idn-LID-2	375	406	422	1531	1594	1625	2672	2672	2609	80.6	121
l'Λdn-LUD-1	594	625	625	1141	1250	1344	3109	3094	3000	102.7	114
l'Λdn-LUD-2	594	641	625	1234	1297	1391	2734	2766	2797	101.3	114
r'edn-RAID-1	438	438	422	1609	1828	1891	1953	2156	2500	118.0	119
r'edn-RAID-2	312	328	328	1687	1828	1891	1952	2086	2276	85.4	117
r'Edn-RED-1	516	547	547	1484	1562	1641	2000	2219	2594	98.0	112
r'Edn-RED-2	438	453	438	1438	1547	1578	1819	2143	2352	91.3	116
r'idn-REED-1	266	266	281	1984	2187	2203	2171	2457	2552	105.0	122
r'idn-REED-2	281	281	312	1891	1984	1937	2162	2422	2578	91.6	120
r'Idn-RID-1	391	438	438	1406	1562	1687	1812	1969	2141	85.7	130
r'Idn-RID-2	438	438	406	1531	1625	1641	1891	1969	1990	70.8	114
r'Λdn-RUD-1	469	562	531	1344	1422	1453	2172	2453	2625	87.0	119
r'Λdn-RUD-2	500	469	422	1391	1406	1406	2062	2266	2391	79.0	115

w'edn-WAID-1	422 406 375	1203 1922 2031	2172 2344 2531	121.4	121
w'edn-WAID-2	359 312 328	1500 1937 1969	2062 2281 2625	107.9	118
w'Edn-WED-1	469 562 594	1016 1344 1547	2391 2438 2495	99.9	110
w'Edn-WED-2	469 562 625	952 1344 1484	2234 2328 2719	97.5	110
w'idn-WEED-1	297 297 312	1438 1984 2062	2156 2250 2547	103.3	125
w'idn-WEED-2	312 312 312	1531 2031 2078	2141 2286 2467	103.1	120
w'Idn-WID-1	359 375 391	1219 1516 1641	2172 2203 2250	79.4	121
w'Idn-WID-2	375 391 391	1156 1359 1533	2190 2181 2190	66.9	119
w'Adn-WUD-1	422 469 484	797 1078 1281	2333 2328 2234	95.0	120
w'Adn-WUD-2	531 547 562	1203 1250 1312	2295 2250 2248	54.7	102
b'Izc-ABYSMAL-1	375 328 312	1875 1844 1703	2750 2813 2859	124.5	119
b'Izc-ABYSMAL-2	381 381 333	1750 1734 1672	2781 2859 2875	121.3	112
d'etc-ACCOMMODATED-1	406 375 375	2000 2047 2062	2813 2844 2734	146.9	102
d'etc-ACCOMMODATED-2	391 359 359	2047 2109 2078	2719 2688 2656	177.1	95
l'etc-ACCUMULATED-1	422 438 422	1734 1875 1937	2547 2641 2688	110.7	101
l'etc-ACCUMULATED-2	375 406 438	1734 1891 1922	2500 2594 2750	113.0	94
d'Alc-ADULTERATED-1	469 457 422	1484 1328 1172	2875 2719 2750	71.5	120
d'Alc-ADULTERATED-2	469 531 500	1422 1219 1078	2719 2703 2750	92.7	115
r'etc-ADULTERATED-1	422 406 391	1859 1969 2016	2422 2641 2688	118.8	105
r'etc-ADULTERATED-2	391 375 359	1797 1922 1953	2203 2406 2672	109.5	96
g'etc-ALLIGATOR-1	297 344 359	2141 2125 2094	2703 2734 2656	169.9	98
g'etc-ALLIGATOR-2	344 344 391	2156 2109 2047	2813 2859 2797	147.4	98
b'Etc-ALPHABET-1	484 547 547	1734 1766 1766	2609 2609 2672	156.1	97
b'Etc-ALPHABET-2	531 594 609	1672 1703 1734	2422 2516 2578	135.7	91
b'Etc-ALPHABETICAL-1	531 562 547	1562 1656 1687	2500 2578 2672	120.2	103
b'Etc-ALPHABETICAL-2	531 562 547	1578 1625 1641	2406 2500 2703	113.1	106
w'etc-ANTIQUATED-1	391 375 359	1859 2047 2047	2250 2381 2625	97.4	99
w'etc-ANTIQUATED-2	375 359 359	1828 2000 2016	2141 2266 2469	110.0	96
t'Ekc-ARCHITECTURE-1	505 531 484	1828 1797 1859	2656 2453 2234	108.8	91
t'Ekc-ARCHITECTURE-2	500 469 419	1719 1734 1828	2547 2312 2238	90.7	96
r'Isc-ARISTOCRATIC-1	422 406 375	1516 1625 1687	1984 2516 2797	81.5	122
r'Isc-ARISTOCRATIC-2	422 406 391	1469 1531 1562	2000 2375 2672	68.7	113
l'Etc-ATHLETIC-1	547 578 578	1219 1406 1500	2734 2703 2656	103.1	105
l'Etc-ATHLETIC-2	531 562 531	1219 1391 1453	2766 2750 2703	106.7	103
z'elc-AZALEA-1	344 453 500	1859 1969 1891	2859 2813 2750	142.1	105
z'elc-AZALEA-2	406 469 531	1828 1828 1672	2813 2781 2719	148.4	108
b'Itc-BITTERSWEET-1	391 422 406	1812 1797 1797	2578 2688 2531	81.3	113
b'Itc-BITTERSWEET-2	406 438 422	1672 1687 1703	2297 2344 2375	67.5	113
w'itc-BITTERSWEET-1	371 343 305	2062 2109 2125	3344 2703 2891	149.8	98
w'itc-BITTERSWEET-2	266 234 234	2109 2141 2094	2476 2657 2848	93.3	87
d'idc-CANDIED-1	281 234 250	2171 2266 2234	3234 3266 3281	138.3	99
d'idc-CANDIED-2	266 266 266	2156 2156 2187	3234 3238 3267	115.6	91
s'Elc-CELEBRATION-1	531 562 562	1406 1281 1188	2781 2781 2813	109.2	105
s'Elc-CELEBRATION-2	500 531 531	1453 1344 1234	2813 2828 2828	87.9	107
r'eSc-CELEBRATION-1	391 344 344	1891 1969 2016	2429 2581 2648	131.7	93
r'eSc-CELEBRATION-2	359 359 344	1891 1953 2000	2229 2438 2619	117.2	96
l'esc-COMPLACENT-1	422 391 297	1891 2031 2109	2688 2703 2750	105.8	113
l'esc-COMPLACENT-2	500 406 312	1609 2047 2141	2688 2734 2750	148.3	107
s'ilc-CONCEAL-1	281 281 297	2125 2172 2172	3031 3125 2953	144.6	119
s'ilc-CONCEAL-2	281 266 297	2187 2250 2219	3094 3219 3172	129.8	114
d'ISc-CONDITION-1	375 391 375	1906 1906 1859	2781 2781 2766	98.9	109
d'ISc-CONDITION-2	438 422 400	1844 1875 1875	2766 2813 2781	111.6	108
r'Itc-CRITICISM-1	391 375 359	1687 1734 1750	2094 2187 2328	44.0	139
r'Itc-CRITICISM-2	391 391 375	1516 1578 1625	1937 2078 2172	51.9	126

s'Izc-CRITICISM-1	391 359 344	1719 1687 1656	2813 2828 2813	113.3	101
s'Izc-CRITICISM-2	359 344 297	1656 1578 1578	2828 2859 2828	90.6	99
r'Λsc-CRUSTACEAN-1	406 453 400	1359 1438 1578	1914 1933 2048	66.1	102
r'Λsc-CRUSTACEAN-2	486 516 486	1469 1484 1547	2016 2219 2563	86.3	110
t'eSc-CRUSTACEAN-1	438 391 312	1953 2031 2047	2733 2688 2734	161.9	114
t'eSc-CRUSTACEAN-2	422 359 297	1922 2078 2078	2844 2859 2857	166.2	114
k'Λsc-CUSTOMARILY-1	590 629 610	1562 1547 1547	2343 2484 2672	78.6	126
k'Λsc-CUSTOMARILY-2	543 562 533	1484 1453 1469	2359 2453 2609	78.9	123
d'ikc-DECREASE-1	297 281 266	2109 2172 2234	3063 3181 3267	107.4	116
d'ikc-DECREASE-2	297 281 250	2016 2047 2125	2875 2984 2981	102.2	114
r'isc-DECREASE-1	297 266 250	2016 2141 2203	2359 2766 3000	144.9	99
r'isc-DECREASE-2	266 234 234	2031 2094 2094	2656 2895 2914	124.8	95
d'Elc-DELTA-1	500 578 609	1766 1469 1266	2797 2734 2766	108.2	107
d'Elc-DELTA-2	453 547 594	1766 1547 1328	2750 2703 2750	103.8	113
d'Etc-DETRIMENT-1	516 594 562	1812 1734 1750	2750 2656 2625	111.0	109
d'Etc-DETRIMENT-2	469 562 562	1859 1687 1656	2750 2609 2609	120.7	111
d'Etc-DETRIMENTAL-1	484 484 500	1891 1812 1781	2734 2672 2656	98.5	124
d'Etc-DETRIMENTAL-2	438 469 422	1766 1687 1656	2828 2781 2797	79.0	116
d'Ilc-DILIGENTLY-1	375 438 406	1766 1562 1297	2750 2703 2672	81.7	116
d'Ilc-DILIGENTLY-2	375 438 422	1766 1547 1359	2813 2766 2797	116.4	119
d'Isc-DISCIPLINE-1	328 344 314	1781 1766 1719	2797 2813 2813	78.5	114
d'Isc-DISCIPLINE-2	328 328 328	1703 1672 1641	2797 2828 2813	68.5	119
d'Isc-DISOBEDIENCE-1	328 344 324	1844 1812 1812	2766 2781 2867	69.7	120
d'Isc-DISOBEDIENCE-2	328 344 328	1859 1781 1766	2844 2859 2859	65.7	124
b'idc-DISOBEDIENCE-1	297 281 281	2047 2094 2125	2719 3067 3203	130.0	106
b'idc-DISOBEDIENCE-2	297 266 281	2062 2094 2125	2797 2875 2990	126.1	112
w'edc-DISSUADED-1	406 391 375	1438 2000 2109	2141 2257 2641	153.8	106
w'edc-DISSUADED-2	375 344 328	1781 2031 2078	2187 2297 2594	122.0	113
b'etc-EXACERBATED-1	422 391 375	1937 2031 2047	2469 2594 2656	166.9	95
b'etc-EXACERBATED-2	344 359 344	1906 2000 2078	2312 2547 2750	137.5	96
t'igc-FATIGUE-1	297 297 281	2141 2187 2203	2990 3105 3105	238.7	109
t'igc-FATIGUE-2	312 297 281	2094 2156 2172	2906 2922 2813	250.8	113
b'Λsc-FILIBUSTER-1	625 625 594	1203 1281 1344	2500 2594 2638	117.0	92
b'Λsc-FILIBUSTER-2	594 625 590	1234 1328 1469	2469 2641 2813	128.5	92
g'izc-FOGEYS-1	266 266 266	2219 2234 2156	2838 2838 2781	223.4	114
g'izc-FOGEYS-2	203 203 266	2203 2203 2078	3031 2938 2719	208.5	88
r'Λsc-FRUSTRATING-1	469 476 476	1297 1359 1406	2312 2469 2531	71.5	117
r'Λsc-FRUSTRATING-2	495 486 486	1375 1438 1500	2328 2484 2688	64.3	120
r'etc-FRUSTRATING-1	391 406 406	1891 1984 1969	2210 2469 2625	114.0	100
r'etc-FRUSTRATING-2	391 375 422	1797 1937 1953	2094 2438 2672	130.6	103
w'Λzc-FUZZY-WUZZY-1	500 531 453	1078 1297 1531	2250 2438 2703	125.6	103
w'Λzc-FUZZY-WUZZY-2	469 500 422	1094 1344 1531	2172 2359 2781	152.8	96
g'etc-GATOR-1	328 297 312	2156 2156 2187	3162 3114 2914	173.3	117
g'etc-GATOR-2	375 375 375	2141 2172 2156	2952 2797 2656	180.2	103
g'izc-GEEZERS-1	250 250 281	2250 2266 2234	3375 3344 3109	168.2	115
g'izc-GEEZERS-2	250 266 281	2187 2203 2187	3314 3267 3094	163.1	109
g'Λtc-GUTTURAL-1	531 594 594	1578 1469 1406	2328 2422 2563	95.9	128
g'Λtc-GUTTURAL-2	469 609 625	1672 1500 1469	2312 2453 2609	125.9	111
l'Λsc-ILLUSTRIOUS-1	578 609 594	1266 1328 1375	2703 2734 2962	102.1	108
l'Λsc-ILLUSTRIOUS-2	531 562 547	1281 1359 1391	2781 2781 2844	109.0	107
r'Edc-INCREDIBLY-1	484 469 484	1469 1484 1578	2016 2156 2375	102.1	122
r'Edc-INCREDIBLY-2	469 516 469	1438 1484 1516	1953 2094 2281	104.1	115
d'isc-INDECENTLY-1	281 250 266	2187 2203 2219	3141 3188 3141	132.9	118
d'isc-INDECENTLY-2	266 266 281	2187 2219 2172	3141 3172 3047	141.0	113

d'Asc-INDUSTRIAL-1	547	578	578	1625	1453	1422	2703	2656	2703	121.3	103
d'Asc-INDUSTRIAL-2	547	594	531	1500	1453	1391	2797	2766	2875	119.6	107
s'Alc-INSULT-1	531	625	625	1438	1312	1188	2875	2813	2719	87.7	104
s'Alc-INSULT-2	562	594	594	1406	1250	1156	2906	2781	2781	106.3	101
b'idc-LOBBIED-1	281	250	266	2078	2094	2156	3000	3266	3234	137.8	105
b'idc-LOBBIED-2	381	305	276	2109	2172	2203	2953	3305	3305	116.2	95
d'Asc-INDUSTRIALIZATION-1	484	516	486	1656	1562	1469	2781	2766	2905	100.0	117
d'Asc-INDUSTRIALIZATION-2	500	500	469	1469	1438	1422	2797	2813	2875	92.3	113
z'eSc-INDUSTRIALIZATION-1	438	453	375	1859	2000	2031	2781	2766	2766	165.5	96
z'eSc-INDUSTRIALIZATION-2	391	375	359	1875	2016	2031	2766	2766	2750	172.7	96
w'Izc-INQUISITIVE-1	359	344	297	1641	1797	1828	2219	2547	2719	65.3	118
w'Izc-INQUISITIVE-2	375	375	328	1453	1672	1719	2219	2422	2766	86.6	124
t'Egc-INTEGRITY-1	500	469	344	1906	1984	2078	2750	2672	2563	94.2	125
t'Egc-INTEGRITY-2	453	500	406	1828	1828	1922	2688	2531	2453	119.4	106
l'izc-ISOSCELES-1	328	312	297	2094	2141	2078	2672	2705	2734	156.9	95
l'izc-ISOSCELES-2	328	281	297	2141	2203	2125	2672	2752	2766	172.2	90
J'ewc-JAYWALKING-1	359	375	359	1969	1969	1969	2641	2625	2406	133.5	123
J'ewc-JAYWALKING-2	359	359	344	1953	2000	2031	2797	2734	2469	114.8	118
d'ezc-LACKADAISICAL-1	406	391	344	2047	2109	2109	2766	2762	2781	176.8	105
d'ezc-LACKADAISICAL-2	406	375	312	2031	2062	1984	2828	2875	2828	164.5	107
l'EJc-LEGISLATOR-1	484	422	469	1469	1547	1641	2672	2688	2750	85.2	119
l'EJc-LEGISLATOR-2	500	500	484	1422	1531	1656	2719	2781	2797	87.5	105
l'etc-LEGISLATOR-1	406	375	375	1953	1969	1891	2766	2734	2672	140.9	96
l'etc-LEGISLATOR-2	453	438	419	1844	1969	1969	2625	2703	2719	92.8	93
l'Itc-LITERATURE-1	375	391	391	1500	1656	1750	2672	2688	2719	87.0	119
l'Itc-LITERATURE-2	391	406	359	1469	1594	1625	2734	2766	2750	71.3	119
l'Itc-LITIGATION-1	391	438	469	1562	1687	1609	2672	2688	2688	113.0	122
l'Itc-LITIGATION-2	391	422	422	1438	1484	1500	2656	2688	2672	71.5	113
g'eSc-LITIGATION-1	375	359	297	2094	2109	2125	2734	2703	2781	180.6	102
g'eSc-LITIGATION-2	344	359	362	2172	2187	2156	2969	2962	2828	167.1	102
l'itc-OBSOLETE-1	344	281	281	2000	2172	2234	2641	2810	2810	162.5	101
l'itc-OBSOLETE-2	344	281	250	2000	2187	2203	2594	2859	2981	174.1	100
l'eSc-POPULATION-1	422	391	328	1812	2000	2062	2703	2781	2781	151.5	107
l'eSc-POPULATION-2	406	359	328	1922	2031	2078	2594	2688	2750	142.2	96
r'Ezc-PRESERVATION-1	516	438	359	1594	1625	1656	2578	2906	3094	79.6	113
r'Ezc-PRESERVATION-2	391	422	406	1438	1516	1484	2219	2625	2953	85.4	112
t'Ekc-PROTECTION-1	562	594	552	1797	1734	1812	2578	2484	2344	91.8	117
t'Ekc-PROTECTION-2	500	594	547	1781	1703	1781	2563	2359	2234	110.8	110
w'izc-QUEASINESS-1	266	266	281	2187	2172	2125	2467	2867	2886	137.9	131
w'izc-QUEASINESS-2	297	281	297	2095	2203	2141	2343	2625	2813	125.0	117
w'Esc-QUESTION-1	578	594	594	1203	1375	1531	2109	2125	2187	87.3	111
w'Esc-QUESTION-2	469	484	476	1281	1422	1562	2156	2172	2234	88.7	120
w'Esc-QUESTIONNAIRE-1	516	524	543	1203	1344	1562	2203	2172	2312	65.4	125
w'Esc-QUESTIONNAIRE-2	453	438	484	1109	1281	1422	2094	2078	2094	95.8	117
r'edc-RADIO-1	359	344	328	1891	2016	2062	2305	2495	2657	130.7	118
r'edc-RADIO-2	391	375	375	1719	1953	2016	2141	2406	2609	141.7	107
b'Atc-REBUTTAL-1	562	578	641	1125	1141	1266	2422	2500	2563	135.0	102
b'Atc-REBUTTAL-2	562	578	594	1125	1172	1281	2406	2453	2638	147.5	103
k'Itc-SCHIZOID-1	344	375	328	1984	1937	1891	2688	2750	2781	52.4	147
k'Itc-SCHIZOID-2	344	359	328	2016	2000	1937	2781	2797	2766	60.0	129
k'Itc-SCHIZOPHRENIC-1	375	391	375	1937	1891	1797	2531	2594	2625	54.2	130
k'Itc-SCHIZOPHRENIC-2	344	375	359	1969	1906	1844	2609	2656	2672	66.7	128
s'iwc-SEAWEED-1	297	281	281	2031	2109	2109	2750	2719	2352	119.7	113
s'iwc-SEAWEED-2	281	266	281	2094	2141	2109	3031	2938	2429	119.1	110

w'idc-SEAWEED-1	266 250 266	2109 2141 2172	2343 2750 2781	173.5	101
w'idc-SEAWEED-2	281 266 297	2141 2203 2203	2297 2688 2733	163.5	89
s'Igc-SIGNATURES-1	344 328 281	1922 2016 2109	2734 2688 2609	83.9	130
s'Igc-SIGNATURES-2	359 328 312	1953 2016 2141	2734 2686 2724	85.5	122
g'Etc-SPAGHETTI-1	359 406 484	2094 2016 1969	3095 2734 2656	129.5	102
g'Etc-SPAGHETTI-2	391 469 500	2062 1984 1922	2844 2719 2703	135.1	104
t'etc-STATEHOUSE-1	375 375 406	1984 2078 2094	2734 2750 2766	130.9	115
t'etc-STATEHOUSE-2	406 422 422	2047 2094 2109	2750 2750 2766	116.2	113
t'Idc-TIDBIT-1	391 406 375	1953 1937 1922	2766 2734 2750	78.5	160
t'Idc-TIDBIT-2	359 344 328	1922 1937 1922	2797 2813 2828	101.9	120
b'Itc-TIDBIT-1	375 438 438	1906 1922 1891	2594 2641 2672	111.0	95
b'Itc-TIDBIT-2	406 453 453	1844 1859 1844	2547 2594 2688	114.4	96
r'izc-UNREASONABLE-1	297 281 281	1984 2078 2078	2781 3000 3063	149.6	121
r'izc-UNREASONABLE-2	333 314 314	1937 2047 2078	2656 2953 3016	114.0	105
w'Izc-VENTRILOQUISM-1	438 438 375	1359 1578 1672	2141 2312 2625	78.3	106
w'Izc-VENTRILOQUISM-2	438 391 281	1453 1578 1578	2187 2453 2734	79.4	99
b'etc-VERBATIM-1	422 391 406	1906 1984 2000	2656 2781 2813	166.9	107
b'etc-VERBATIM-2	391 344 344	1969 2078 2141	2703 2766 2797	169.4	115
b'Izr-ABYSMAL-1	422 328 328	1766 1750 1672	2781 2938 2969	115.1	119
b'Izr-ABYSMAL-2	406 375 344	1797 1781 1766	2705 2686 2676	73.3	112
b'Izr-ABYSMAL-3	406 375 375	1797 1734 1672	2766 3031 3031	88.6	80
b'Izr-ABYSMAL-4	406 406 375	1812 1844 1797	2672 2922 2969	63.8	142
b'Izr-ABYSMAL-5	406 391 391	1766 1734 1687	2828 2859 2844	55.2	102
d'etr-ACCOMMODATED-1	438 453 438	2141 2156 2109	2906 2844 2672	117.5	89
d'etr-ACCOMMODATED-2	406 406 391	2156 2203 2141	2766 2703 2719	145.2	88
d'etr-ACCOMMODATED-3	422 422 422	1953 2016 1984	2656 2656 2594	140.1	88
d'etr-ACCOMMODATED-4	438 406 391	2047 2094 2109	2891 2938 2906	144.4	82
d'etr-ACCOMMODATED-5	453 438 406	1875 2016 2016	2547 2609 2609	119.0	89
l'etr-ACCUMULATED-1	453 438 438	1797 1859 1891	2531 2594 2641	94.0	114
l'etr-ACCUMULATED-2	438 438 453	1656 1812 1859	2641 2656 2703	75.7	108
l'etr-ACCUMULATED-3	453 484 453	1484 1672 1797	2688 2703 2719	70.5	98
l'etr-ACCUMULATED-4	453 453 438	1687 1828 1844	2719 2719 2688	88.6	96
l'etr-ACCUMULATED-5	438 422 438	1812 2000 1984	2531 2625 2625	112.3	90
d'Alr-ADULTERATED-1	406 438 469	1516 1422 1312	2766 2688 2594	29.3	115
d'Alr-ADULTERATED-2	500 578 578	1516 1250 1094	2438 2563 2813	67.9	101
d'Alr-ADULTERATED-3	484 469 453	1594 1531 1391	2734 2703 2641	33.9	119
d'Alr-ADULTERATED-4	516 516 484	1328 1031 984	2625 2734 2857	123.2	123
d'Alr-ADULTERATED-5	500 516 516	1594 1344 1219	2813 2781 2859	83.3	119
r'etr-ADULTERATED-1	406 391 375	1953 2094 2141	2312 2419 2719	80.9	101
r'etr-ADULTERATED-2	453 438 391	1750 1937 2031	2187 2375 2484	97.0	91
r'etr-ADULTERATED-3	422 406 406	1734 1859 1891	2109 2281 2391	94.6	98
r'etr-ADULTERATED-4	438 438 422	1594 1781 1875	2109 2250 2422	93.4	110
r'etr-ADULTERATED-5	391 375 359	1703 1906 1953	2078 2219 2484	99.8	96
g'etr-ALLIGATOR-1	457 505 543	2057 2067 1971	2629 2714 2714	70.0	86
g'etr-ALLIGATOR-2	344 406 438	2181 2162 1905	2969 2969 2875	141.8	139
g'etr-ALLIGATOR-3	344 406 438	2219 2156 2094	2656 2781 2750	115.0	86
g'etr-ALLIGATOR-4	419 419 429	2171 2124 2124	2657 2790 2838	98.2	85
g'etr-ALLIGATOR-5	375 438 429	2219 2094 1943	2705 2695 2686	91.5	144
b'Etr-ALPHABET-1	500 531 500	1656 1766 1844	2438 2469 2516	81.8	86
b'Etr-ALPHABET-2	484 484 469	1594 1625 1641	2422 2484 2563	51.3	96
b'Etr-ALPHABET-3	484 531 531	1594 1703 1797	2406 2500 2578	82.2	114
b'Etr-ALPHABET-4	469 453 391	1703 1812 1766	2578 2859 2922	63.6	116
b'Etr-ALPHABET-5	531 562 547	1672 1687 1672	2453 2484 2609	98.7	89
b'Etr-ALPHABETICAL-1	531 594 590	1531 1594 1609	2422 2500 2469	64.9	100

b'Etr-ALPHABETICAL-2	562 594 562	1547 1578 1609	2453 2531 2453	73.4	96
b'Etr-ALPHABETICAL-3	516 578 547	1422 1531 1562	2375 2531 2563	61.3	96
b'Etr-ALPHABETICAL-4	531 562 547	1500 1516 1516	2563 2656 2656	57.1	99
b'Etr-ALPHABETICAL-5	531 578 562	1609 1656 1656	2625 2766 2797	58.9	102
w'etr-ANTIQUATED-1	406 406 406	1750 1906 1937	2219 2312 2406	62.5	103
w'etr-ANTIQUATED-2	406 406 406	1906 2000 1969	2250 2352 2656	58.2	104
w'etr-ANTIQUATED-3	406 406 406	1781 1906 1937	2281 2375 2531	68.7	101
w'etr-ANTIQUATED-4	406 375 375	1937 2000 1969	2344 2531 2563	87.0	99
w'etr-ANTIQUATED-5	406 406 375	1844 1969 1969	2250 2343 2688	76.6	98
t'Ekr-ARCHITECTURE-1	552 562 500	1790 1687 1781	2438 2276 2125	86.1	188
t'Ekr-ARCHITECTURE-2	514 531 533	1771 1750 1844	2486 2312 2250	87.6	101
t'Ekr-ARCHITECTURE-3	766 590 552	1914 1848 1829	2638 2352 2305	82.3	0
t'Ekr-ARCHITECTURE-4	467 438 438	1812 1867 1875	2314 2286 2248	43.8	92
t'Ekr-ARCHITECTURE-5	543 562 514	1867 1848 1905	2733 2371 2200	94.4	92
r'Isr-ARISTOCRATIC-1	438 391 359	1687 1734 1781	2266 2500 2813	43.8	122
r'Isr-ARISTOCRATIC-2	422 422 406	1375 1516 1594	1797 1953 2229	78.6	120
r'Isr-ARISTOCRATIC-3	406 406 406	1516 1594 1687	1733 1969 2125	49.7	108
r'Isr-ARISTOCRATIC-4	391 438 422	1453 1609 1641	1937 2016 2162	86.1	147
r'Isr-ARISTOCRATIC-5	406 375 344	1297 1406 1516	1641 1734 2047	76.1	122
l'Etr-ATHLETIC-1	484 562 594	1094 1359 1516	3125 2953 2969	118.5	118
l'Etr-ATHLETIC-2	453 547 578	1078 1344 1438	2797 2828 2828	93.6	118
l'Etr-ATHLETIC-3	531 594 609	1312 1453 1531	2781 2766 2734	78.8	108
l'Etr-ATHLETIC-4	531 516 547	1312 1453 1500	2750 2797 2766	87.8	110
l'Etr-ATHLETIC-5	531 562 594	1297 1438 1516	2750 2797 2766	110.7	115
z'elr-AZALEA-1	438 469 484	1859 1719 1578	2859 2750 2750	100.7	110
z'elr-AZALEA-2	422 438 516	1984 1969 1703	2844 2766 2703	124.7	85
z'elr-AZALEA-3	344 406 438	2156 2125 2000	2875 2797 2656	88.8	86
z'elr-AZALEA-4	406 438 469	2000 1984 1734	2828 2766 2703	127.7	106
z'elr-AZALEA-5	359 422 500	2062 2047 1828	2828 2766 2734	117.5	99
b'Itr-BITTERSWEET-1	422 422 406	1781 1766 1750	2797 2906 2938	44.5	105
b'Itr-BITTERSWEET-2	422 438 422	1781 1781 1766	2516 2609 2500	52.5	114
b'Itr-BITTERSWEET-3	422 453 453	1687 1703 1703	2391 2484 2422	52.9	118
b'Itr-BITTERSWEET-4	406 406 406	1719 1719 1781	2469 2563 2625	46.5	129
b'Itr-BITTERSWEET-5	438 438 422	1703 1719 1734	2484 2391 2312	41.3	112
w'itr-BITTERSWEET-1	234 219 188	2234 2234 2234	2610 2848 3000	77.5	101
w'itr-BITTERSWEET-2	297 266 234	1953 2172 2219	2219 2344 2543	80.4	106
w'itr-BITTERSWEET-3	312 281 250	1750 2109 2156	2171 2400 2828	93.5	102
w'itr-BITTERSWEET-4	312 297 234	2062 2187 2187	2312 2547 2797	71.6	116
w'itr-BITTERSWEET-5	312 344 312	1344 2000 2141	2109 2203 2578	86.9	98
d'idr-CANDIED-1	305 286 248	2281 2266 2187	2984 3094 3219	71.7	99
d'idr-CANDIED-2	281 281 297	2219 2234 2203	3000 3031 3047	78.0	120
d'idr-CANDIED-3	276 248 250	2266 2328 2328	3266 3344 3375	79.2	103
d'idr-CANDIED-4	312 266 297	2172 2234 2234	2828 2891 2844	71.7	130
d'idr-CANDIED-5	359 328 312	2125 2156 2156	2844 2891 2859	68.0	96
s'Elr-CELEBRATION-1	531 547 516	1375 1281 1031	2828 2844 2953	87.2	138
s'Elr-CELEBRATION-2	406 500 500	1312 1124 1000	2844 2828 2859	84.8	155
s'Elr-CELEBRATION-3	500 531 516	1344 1266 1219	2828 2844 2906	55.2	119
s'Elr-CELEBRATION-4	531 547 531	1391 1297 1203	2766 2781 2813	81.9	103
s'Elr-CELEBRATION-5	500 516 547	1328 1219 1156	2819 2857 2962	69.8	95
r'eSr-CELEBRATION-1	438 406 391	1781 1922 2016	2172 2328 2609	111.3	105
r'eSr-CELEBRATION-2	406 406 391	1484 1750 1859	1937 2095 2344	117.9	138
r'eSr-CELEBRATION-3	438 375 359	1734 1875 1953	2094 2391 2667	109.1	98
r'eSr-CELEBRATION-4	453 438 359	1703 1891 2016	2297 2641 2797	107.5	92
r'eSr-CELEBRATION-5	438 422 406	1750 1875 1953	2281 2469 2609	104.3	90

l'esr-COMPLACENT-1	484 453 406	1562 1937 2016	2609 2703 2750	144.6	105
l'esr-COMPLACENT-2	484 453 359	1687 2078 2125	2547 2578 2672	137.9	123
l'esr-COMPLACENT-3	469 438 375	1641 1969 2094	2516 2563 2672	123.0	101
l'esr-COMPLACENT-4	438 391 359	1766 2031 2078	2500 2719 2734	99.4	100
l'esr-COMPLACENT-5	422 391 375	1469 1906 2141	2672 2719 2828	132.3	133
s'ilr-CONCEAL-1	0 406 500	0 1984 1703	0 2531 2563	138.0	143
s'ilr-CONCEAL-2	344 422 422	1937 1750 1484	2484 2422 2438	77.9	110
s'ilr-CONCEAL-3	359 422 438	1875 1594 1391	2547 2531 2609	92.5	119
s'ilr-CONCEAL-4	328 375 391	2156 2094 1922	2734 2625 2563	73.6	100
s'ilr-CONCEAL-5	328 375 391	2031 1906 1594	2531 2453 2469	107.7	127
d'ISr-CONDITION-1	422 422 422	1906 1906 1891	2875 2906 2938	83.0	113
d'ISr-CONDITION-2	391 391 406	1859 1828 1844	2750 2828 2813	63.7	172
d'ISr-CONDITION-3	406 406 406	1734 1703 1687	2688 2719 2703	65.2	136
r'Itr-CRITICISM-1	469 469 391	1484 1578 1609	2000 2062 2047	48.8	174
r'Itr-CRITICISM-2	422 438 438	1531 1641 1656	2000 2094 2125	53.0	117
r'Itr-CRITICISM-3	406 422 391	1547 1656 1719	1969 2109 2219	97.2	136
r'Itr-CRITICISM-4	359 391 391	1469 1531 1562	1953 1984 2078	41.5	131
r'Itr-CRITICISM-5	422 391 375	1547 1656 1703	1906 2000 2125	71.1	120
s'Izr-CRITICISM-1	359 375 344	1703 1687 1594	2844 2875 2844	88.1	151
s'Izr-CRITICISM-2	375 359 344	1703 1687 1625	2813 2828 2813	90.3	89
s'Izr-CRITICISM-3	359 344 344	1703 1703 1609	2875 2859 2875	127.5	122
s'Izr-CRITICISM-4	391 406 359	1656 1641 1609	2844 2859 2875	112.8	86
s'Izr-CRITICISM-5	391 375 359	1672 1656 1625	2891 2875 2922	99.6	98
r'Asr-CRUSTACEAN-1	562 578 578	1453 1469 1547	2125 2266 2375	77.4	104
r'Asr-CRUSTACEAN-2	594 609 609	1375 1453 1516	2156 2406 2438	72.0	108
r'Asr-CRUSTACEAN-3	531 516 281	1328 1438 1500	1953 2125 2438	64.0	118
r'Asr-CRUSTACEAN-4	484 469 500	1359 1375 1500	1922 2094 2453	71.5	113
r'Asr-CRUSTACEAN-5	547 578 600	1422 1531 1594	2048 2344 2469	79.4	127
t'eSr-CRUSTACEAN-1	422 390 333	2000 2062 2076	2922 2922 2844	116.7	108
t'eSr-CRUSTACEAN-2	422 406 400	2016 2062 2062	2891 2906 2828	117.8	109
t'eSr-CRUSTACEAN-3	406 375 312	2031 2141 2141	2906 2938 2828	132.6	152
t'eSr-CRUSTACEAN-4	422 422 406	1969 2062 2094	2953 2969 2969	151.2	112
t'eSr-CRUSTACEAN-5	328 297 297	2062 2109 2094	2922 2953 2938	113.7	123
k'Asr-CUSTOMARILY-1	590 609 562	1594 1578 1562	2516 2578 2571	81.2	174
k'Asr-CUSTOMARILY-2	609 594 609	1531 1500 1500	2500 2547 2581	63.5	123
k'Asr-CUSTOMARILY-3	562 578 562	1547 1531 1531	2438 2531 2594	63.3	121
k'Asr-CUSTOMARILY-4	656 656 641	1516 1516 1531	2469 2484 2667	55.0	121
k'Asr-CUSTOMARILY-5	638 714 657	1625 1578 1516	2531 2625 2828	77.0	178
d'ikr-DECREASE-1	250 250 250	2031 2078 2172	3063 3125 3156	100.0	121
d'ikr-DECREASE-2	281 219 266	2125 2172 2141	3000 3094 3203	67.8	103
d'ikr-DECREASE-3	281 281 297	2125 2187 2281	2938 3057 3200	99.0	113
d'ikr-DECREASE-4	250 234 250	2219 2234 2281	3125 3125 3141	78.9	111
d'ikr-DECREASE-5	266 266 250	2266 2297 2297	3125 3125 3156	83.4	114
r'isr-DECREASE-1	297 281 266	1969 2062 2078	2590 3016 3000	112.6	99
r'isr-DECREASE-2	328 328 328	2094 2125 2109	2543 2914 2952	88.0	92
r'isr-DECREASE-3	312 312 312	2062 2141 2094	2267 2410 2552	70.6	109
r'isr-DECREASE-4	312 297 281	2109 2172 2187	2476 2771 2971	110.9	94
r'isr-DECREASE-5	328 312 297	2016 2141 2156	2429 2867 3019	96.2	105
d'Elr-DELTA-1	625 625 500	1484 1203 1031	2766 2781 2906	130.8	93
d'Elr-DELTA-2	547 625 656	1687 1469 1234	2766 2688 2672	88.6	98
d'Elr-DELTA-3	594 609 547	1531 1250 1031	2766 2813 2938	123.3	89
d'Elr-DELTA-4	500 562 594	1734 1531 1281	2719 2578 2609	94.2	99
d'Elr-DELTA-5	516 578 594	1672 1469 1266	2672 2656 2672	98.3	95
d'Etr-DETRIMENT-1	531 562 469	1734 1703 1703	2797 2828 2922	77.0	109

d'Etr-DETRIMENT-2	453 547 467	2031 1969 1943	2922 2922 2914	82.4	144
d'Etr-DETRIMENT-3	516 578 484	1734 1641 1641	2719 2719 3000	95.7	106
d'Etr-DETRIMENT-4	500 500 469	1719 1687 1687	2813 2705 2734	69.7	109
d'Etr-DETRIMENT-5	531 594 594	1781 1734 1734	2563 2547 2625	80.4	103
d'Etr-DETRIMENTAL-1	453 469 453	1844 1797 1781	2719 2703 2688	61.1	116
d'Etr-DETRIMENTAL-2	484 484 438	1656 1687 1656	2828 2844 2844	59.3	102
d'Etr-DETRIMENTAL-3	453 453 438	1891 1797 1766	2953 2953 3078	79.8	117
d'Etr-DETRIMENTAL-4	453 500 516	1906 1781 1719	2781 2594 2750	99.0	112
d'Etr-DETRIMENTAL-5	438 469 453	1797 1750 1703	2563 2547 2594	70.2	110
d'Ilr-DILIGENTLY-1	391 406 406	1656 1453 1266	2750 2641 2641	60.6	132
d'Ilr-DILIGENTLY-2	422 453 469	1719 1609 1328	2766 2719 2656	78.1	120
d'Ilr-DILIGENTLY-3	375 391 422	1766 1578 1344	2938 2891 2859	98.8	137
d'Ilr-DILIGENTLY-4	453 469 469	1734 1469 1203	2609 2688 2797	87.7	90
d'Ilr-DILIGENTLY-5	438 438 438	1562 1359 1219	2656 2719 2750	84.4	112
d'Isr-DISCIPLINE-1	359 344 344	1750 1703 1750	2906 2906 3000	52.9	110
d'Isr-DISCIPLINE-2	375 344 297	1812 1797 1766	2859 2953 2953	56.5	119
d'Isr-DISCIPLINE-3	391 391 375	1641 1641 1625	2750 2797 2828	55.6	118
d'Isr-DISCIPLINE-4	391 406 406	1625 1625 1609	2813 2859 2859	56.5	106
d'Isr-DISCIPLINE-5	406 422 406	1734 1719 1719	2875 2938 2953	69.1	126
d'Isr-DISOBEDIENCE-1	375 391 248	1891 1906 1906	2813 2859 2875	65.3	105
d'Isr-DISOBEDIENCE-2	375 375 375	1828 1812 1844	2844 2844 2938	66.5	120
d'Isr-DISOBEDIENCE-3	328 344 343	1828 1797 1828	2828 2813 2813	62.9	97
d'Isr-DISOBEDIENCE-4	328 359 359	1797 1766 1734	2875 2844 2922	74.7	101
d'Isr-DISOBEDIENCE-5	359 328 328	1812 1797 1781	2766 2828 2859	47.8	116
b'idr-DISOBEDIENCE-1	297 266 266	2062 2078 2109	2875 3000 3047	77.8	99
b'idr-DISOBEDIENCE-2	312 344 328	2094 2156 2187	2719 2828 2938	73.6	101
b'idr-DISOBEDIENCE-3	312 297 281	2156 2219 2234	2828 3000 3047	94.6	94
b'idr-DISOBEDIENCE-4	312 312 312	2141 2141 2156	2781 3016 3016	52.7	103
b'idr-DISOBEDIENCE-5	312 312 410	2000 2109 2203	2375 2734 2938	105.6	105
w'edr-DISSUADED-1	375 375 406	1844 2000 2031	2281 2375 2438	63.5	100
w'edr-DISSUADED-2	406 406 375	1937 1969 1969	2375 2500 2625	83.6	129
w'edr-DISSUADED-3	406 406 406	1906 2000 2031	2344 2406 2438	77.4	92
w'edr-DISSUADED-4	438 438 406	1844 1875 1875	2375 2500 2625	89.6	102
w'edr-DISSUADED-5	375 375 375	2000 2000 1969	2344 2531 2563	92.2	125
b'etr-EXACERBATED-1	391 391 375	1828 1922 1953	2344 2500 2667	148.7	96
b'etr-EXACERBATED-2	438 438 422	1984 2000 1922	2734 2781 2703	156.5	84
b'etr-EXACERBATED-3	422 406 422	1937 2016 2078	2625 2719 2688	99.9	90
b'etr-EXACERBATED-4	438 438 438	1906 2000 1984	2594 2734 2734	96.3	94
b'etr-EXACERBATED-5	422 422 422	1875 1922 1891	2391 2578 2672	104.0	107
t'igr-FATIGUE-1	312 328 328	2156 2187 2219	3281 3266 3281	180.6	94
t'igr-FATIGUE-2	312 312 266	2125 2156 2203	3190 3257 3200	91.4	88
t'igr-FATIGUE-3	312 297 297	2203 2234 2266	3109 3190 0	96.0	127
t'igr-FATIGUE-4	297 297 281	2156 2203 2250	3248 3276 3257	123.3	129
t'igr-FATIGUE-5	328 297 281	2141 2156 2219	3031 3172 3188	140.3	97
b'Asr-FILIBUSTER-1	609 656 641	1172 1266 1344	2500 2578 2641	110.1	96
b'Asr-FILIBUSTER-2	625 625 594	1266 1359 1500	2578 2656 2734	97.5	91
b'Asr-FILIBUSTER-3	594 625 578	1219 1297 1406	2531 2594 2703	102.2	87
b'Asr-FILIBUSTER-4	594 609 562	1312 1375 1422	2438 2641 2828	106.9	82
b'Asr-FILIBUSTER-5	594 641 594	1266 1375 1453	2391 2547 2875	110.6	93
g'izr-FOGEYS-1	362 333 295	2156 2141 2109	2610 2813 2819	116.8	103
g'izr-FOGEYS-2	297 328 328	2187 2203 2172	2505 2656 2766	111.4	117
g'izr-FOGEYS-3	328 328 328	2133 2141 2109	2305 2543 2625	121.5	88
g'izr-FOGEYS-4	281 297 312	2257 2171 2125	2495 2594 2781	130.7	90
g'izr-FOGEYS-5	281 297 297	2114 2086 2076	2343 2343 2438	116.9	108

r'Asr-FRUSTRATING-1	609 609 0	1328 1406 1578	2078 2171 2429	63.9	105
r'Asr-FRUSTRATING-2	578 594 531	1328 1391 1469	2203 2344 2500	51.3	143
r'Asr-FRUSTRATING-3	578 578 516	1344 1375 1516	2125 2328 2563	65.5	151
r'Asr-FRUSTRATING-4	531 547 581	1234 1359 1516	1891 2187 2391	63.3	174
r'Asr-FRUSTRATING-5	562 609 594	1328 1391 1500	2047 2187 2328	89.0	109
r'etr-FRUSTRATING-1	453 469 453	1844 1859 1844	2266 2375 2578	41.5	0
r'etr-FRUSTRATING-2	422 469 469	1937 1969 1969	2250 2312 2391	74.6	213
r'etr-FRUSTRATING-3	484 484 505	1750 1844 1906	2281 2422 2500	77.2	93
r'etr-FRUSTRATING-4	438 438 422	1734 1812 1875	2234 2344 2516	63.3	114
r'etr-FRUSTRATING-5	438 438 438	1719 1781 1859	2109 2250 2391	117.0	88
w'Azr-FUZZY-WUZZY-1	484 562 516	1016 1266 1531	2297 2406 2641	119.0	92
w'Azr-FUZZY-WUZZY-2	516 562 531	1031 1297 1578	2281 2438 2578	132.5	118
w'Azr-FUZZY-WUZZY-3	469 500 484	1094 1297 1438	2203 2344 2438	97.2	96
w'Azr-FUZZY-WUZZY-4	562 578 469	1281 1469 1562	2406 2581 2971	131.5	99
w'Azr-FUZZY-WUZZY-5	500 531 469	1219 1406 1656	2250 2344 2578	112.6	98
g'etr-GATOR-1	312 344 344	2187 2187 2156	3000 3000 2969	116.3	119
g'etr-GATOR-2	312 375 406	2187 2156 2031	2906 2875 2875	88.6	134
g'etr-GATOR-3	344 406 406	2187 2187 2094	2969 2938 2813	112.0	106
g'etr-GATOR-4	281 312 312	2062 2094 2062	2688 2719 2724	132.3	113
g'etr-GATOR-5	344 344 419	2250 2219 2076	3063 3063 2924	134.7	144
g'izr-GEEZERS-1	352 362 352	2250 2266 2234	3016 3031 2953	136.7	96
g'izr-GEEZERS-2	266 297 297	2250 2266 2141	3219 3143 2750	149.1	109
g'izr-GEEZERS-3	328 344 312	2234 2203 2172	3000 2828 2703	152.7	86
g'izr-GEEZERS-4	381 381 362	2297 2281 2250	3328 3281 2971	101.4	79
g'izr-GEEZERS-5	266 266 266	2281 2297 2219	3000 3048 2828	157.9	91
g'Atr-GUTTURAL-1	547 641 656	1672 1531 1469	2375 2438 2484	78.8	110
g'Atr-GUTTURAL-2	594 625 609	1562 1484 1469	2344 2406 2516	90.3	105
g'Atr-GUTTURAL-3	516 578 562	1609 1438 1422	2250 2422 2500	91.0	118
g'Atr-GUTTURAL-4	609 656 625	1500 1453 1406	2359 2500 2609	85.6	109
g'Atr-GUTTURAL-5	547 594 625	1562 1484 1438	2297 2391 2531	84.6	103
l'Asr-ILLUSTRIOUS-1	594 656 609	1219 1312 1391	2969 2938 2953	108.6	114
l'Asr-ILLUSTRIOUS-2	625 641 578	1297 1344 1438	2719 2703 2922	109.8	111
l'Asr-ILLUSTRIOUS-3	578 609 594	1344 1391 1484	2859 2922 3016	92.6	148
l'Asr-ILLUSTRIOUS-4	531 578 562	1312 1391 1422	2719 2813 3000	104.4	134
l'Asr-ILLUSTRIOUS-5	578 594 547	1125 1266 1375	2943 2962 2905	91.0	136
r'Edr-INCREDIBLY-1	453 453 438	1375 1406 1438	1891 2047 2141	75.9	114
r'Edr-INCREDIBLY-2	516 562 578	1656 1656 1625	2234 2422 2578	95.4	143
r'Edr-INCREDIBLY-3	531 562 516	1562 1578 1594	2266 2391 2453	57.7	125
r'Edr-INCREDIBLY-4	486 562 547	1500 1469 1500	2094 2219 2328	77.4	167
r'Edr-INCREDIBLY-5	516 531 531	1562 1594 1578	2297 2438 2516	66.8	121
d'isr-INDECENTLY-1	266 250 266	2281 2281 2281	3312 3297 3125	103.4	119
d'isr-INDECENTLY-2	266 266 297	2328 2312 2234	3156 3141 2938	120.6	133
d'isr-INDECENTLY-3	281 266 281	2266 2281 2281	3162 3181 3152	83.0	128
d'isr-INDECENTLY-4	266 266 266	2312 2344 2281	3234 3266 3141	110.6	118
d'isr-INDECENTLY-5	266 266 281	2219 2234 2234	3250 3266 3172	100.2	129
d'Asr-INDUSTRIAL-1	578 578 531	1609 1531 1453	2844 2922 3000	81.0	107
d'Asr-INDUSTRIAL-2	594 625 578	1641 1500 1484	2781 2891 2969	82.6	109
d'Asr-INDUSTRIAL-3	547 594 547	1609 1516 1531	2719 2688 2891	97.5	122
d'Asr-INDUSTRIAL-4	500 516 500	1656 1594 1562	2797 2922 3047	81.3	127
d'Asr-INDUSTRIAL-5	453 484 469	1609 1562 1484	2848 2990 3067	73.6	110
d'Asr-INDUSTRIALIZATION-1	531 578 578	1734 1641 1609	2828 2844 2844	108.6	145
d'Asr-INDUSTRIALIZATION-2	547 547 500	1625 1547 1531	2906 2922 2984	80.0	120
d'Asr-INDUSTRIALIZATION-3	594 609 533	1562 1500 1484	2719 2641 2703	94.6	110
d'Asr-INDUSTRIALIZATION-4	500 594 581	1719 1625 1594	2875 2859 2906	88.4	139

d'Asr-INDUSTRIALIZATION-5	500 516 476	1562 1516 1500	2891 3047 3000	79.1	95
z'eSr-INDUSTRIALIZATION-1	438 406 359	1875 2000 2062	2797 2750 2781	129.5	118
z'eSr-INDUSTRIALIZATION-2	422 406 406	1875 2031 2047	2844 2891 2859	157.3	101
z'eSr-INDUSTRIALIZATION-3	422 391 375	1922 2031 2047	2703 2594 2625	150.5	98
z'eSr-INDUSTRIALIZATION-4	438 422 375	1891 2016 2094	2703 2656 2672	135.0	111
z'eSr-INDUSTRIALIZATION-5	391 422 359	1859 1984 2000	2906 3094 3016	129.2	91
w'Izr-INQUISITIVE-1	422 391 359	1562 1672 1687	2250 2590 2750	54.0	93
w'Izr-INQUISITIVE-2	359 375 344	1141 1516 1766	2328 2344 2790	91.4	117
w'Izr-INQUISITIVE-3	406 375 286	1625 1750 1781	2328 2500 2766	62.1	154
w'Izr-INQUISITIVE-4	359 375 391	1391 1625 1734	2375 2438 2875	66.6	193
w'Izr-INQUISITIVE-5	406 391 359	1703 1734 1734	2422 2531 2672	51.4	98
s'Alr-INSULT-1	516 547 531	1250 1188 1094	2734 2828 2859	74.9	103
s'Alr-INSULT-2	609 594 562	1328 1203 1141	2813 3114 3156	110.6	84
s'Alr-INSULT-3	578 609 562	1422 1219 1078	2609 2734 2969	131.0	98
s'Alr-INSULT-4	547 578 547	1219 1078 953	2828 2828 2828	73.3	93
s'Alr-INSULT-5	594 594 578	1391 1281 1172	2594 2594 2609	111.9	100
t'Egr-INTEGRITY-1	514 500 406	1812 1812 1969	2771 2688 2469	101.9	106
t'Egr-INTEGRITY-2	524 467 406	1933 2000 2125	2771 2686 2514	81.0	115
t'Egr-INTEGRITY-3	524 457 429	1937 2031 2156	2724 2594 2531	80.3	92
t'Egr-INTEGRITY-4	419 390 333	2031 2125 2250	2829 2686 2514	87.4	120
t'Egr-INTEGRITY-5	469 406 344	1943 2031 2105	2733 2533 2362	88.6	99
l'izr-ISOSCELES-1	375 344 328	1781 2109 2078	2531 2656 2714	120.0	92
l'izr-ISOSCELES-2	391 371 371	1906 2047 2062	2578 2703 2750	93.5	98
l'izr-ISOSCELES-3	375 328 312	1906 2016 2047	2672 2734 2734	81.4	96
l'izr-ISOSCELES-4	312 266 266	1984 2141 2094	2609 2766 2781	121.5	100
l'izr-ISOSCELES-5	375 359 312	1797 2016 2094	2625 2688 2766	78.7	102
J'ewr-JAYWALKING-1	406 406 406	2062 2094 1937	2695 2438 2219	96.6	86
J'ewr-JAYWALKING-2	375 344 375	2062 2094 2094	2625 2563 2469	99.3	123
J'ewr-JAYWALKING-3	438 438 469	1875 1875 1524	2469 2266 2203	123.4	172
J'ewr-JAYWALKING-4	375 406 406	2000 2031 2031	2813 2719 2375	105.8	104
J'ewr-JAYWALKING-5	375 375 375	2000 2062 2031	2750 2656 2219	105.8	82
d'ezr-LACKADAISICAL-1	422 406 422	2031 2078 2000	2875 2875 2891	123.8	103
d'ezr-LACKADAISICAL-2	391 375 344	2078 2125 2000	2766 2848 2922	138.6	97
d'ezr-LACKADAISICAL-3	391 375 375	2141 2125 1984	2781 2766 2750	132.7	94
d'ezr-LACKADAISICAL-4	375 359 359	2203 2219 2094	2875 2906 2828	131.8	108
d'ezr-LACKADAISICAL-5	391 375 375	2109 2172 2094	2905 2943 2922	119.8	101
l'EJr-LEGISLATOR-1	578 562 516	1484 1578 1641	2750 2797 2672	71.9	134
l'EJr-LEGISLATOR-2	500 562 531	1188 1500 1656	3067 2953 2922	95.0	132
l'EJr-LEGISLATOR-3	469 419 375	1500 1625 1734	2734 2734 2703	76.2	95
l'EJr-LEGISLATOR-4	453 484 484	1328 1500 1578	2875 2844 2844	76.1	160
l'EJr-LEGISLATOR-5	516 516 469	1406 1562 1687	2656 2688 2703	96.2	92
l'etr-LEGISLATOR-1	500 500 438	1594 1875 1984	2609 2657 2667	119.0	105
l'etr-LEGISLATOR-2	453 453 438	1516 1844 2016	2672 2688 2886	105.0	92
l'etr-LEGISLATOR-3	453 406 359	1781 2078 2203	2625 2724 2924	109.4	84
l'etr-LEGISLATOR-4	453 453 438	1484 1797 1937	2625 2641 2688	90.3	115
l'etr-LEGISLATOR-5	500 469 438	1844 1984 1875	2734 2828 2750	103.0	211
l'Itr-LITERATURE-1	422 422 406	1547 1687 1719	2719 2672 2703	71.1	94
l'Itr-LITERATURE-2	469 484 484	1406 1547 1609	2859 2813 2813	73.0	117
l'Itr-LITERATURE-3	469 469 438	1562 1656 1672	2813 2813 2859	58.8	96
l'Itr-LITERATURE-4	453 469 406	1562 1656 1641	2797 2828 2844	59.4	94
l'Itr-LITERATURE-5	406 422 406	1703 1719 1719	2672 2688 2688	51.3	104
l'Itr-LITIGATION-1	422 453 453	1516 1625 1625	2484 2609 2641	70.6	115
l'Itr-LITIGATION-2	453 469 406	1609 1672 1656	2750 2734 2734	78.2	127
l'Itr-LITIGATION-3	375 375 391	1609 1750 1766	2762 2828 2790	76.6	193

l'Itr-LITIGATION-4	391 422 422	1547 1641 1687	2375 2484 2563	82.2	110
l'Itr-LITIGATION-5	391 391 391	1734 1734 1703	2547 2531 2594	75.7	136
g‘eSr-LITIGATION-1	391 375 328	2187 2234 2234	2895 3010 3057	144.6	102
g‘eSr-LITIGATION-2	391 391 359	2172 2203 2172	2938 2953 2953	147.1	112
g‘eSr-LITIGATION-3	406 391 375	2203 2250 2172	3172 3133 3133	139.8	144
g‘eSr-LITIGATION-4	391 391 375	2125 2125 2141	3172 3125 3156	164.5	99
g‘eSr-LITIGATION-5	375 375 344	2141 2203 2219	3019 2922 2938	139.8	137
b'idr-LOBBIED-1	381 371 362	1891 1969 2031	2422 2703 2813	51.9	125
b'idr-LOBBIED-2	362 352 333	2062 2172 2250	2581 2733 3038	54.5	136
b'idr-LOBBIED-3	467 438 419	1781 2125 2109	2250 2563 2610	99.9	151
b'idr-LOBBIED-4	328 359 359	2047 2062 2047	2609 2848 2875	61.7	104
b'idr-LOBBIED-5	381 371 324	2187 2172 2187	2719 2906 2922	42.5	99
l‘itr-OBSOLETE-1	375 297 281	2000 2203 2266	2641 2813 2971	132.9	105
l‘itr-OBSOLETE-2	328 312 297	2031 2203 2250	2609 2734 2906	112.6	110
l‘itr-OBSOLETE-3	359 344 328	1875 2094 2219	2531 2594 2819	104.4	95
l‘itr-OBSOLETE-4	344 328 312	2016 2141 2203	2610 2800 2876	83.8	91
l‘itr-OBSOLETE-5	328 328 344	1969 2172 2156	2563 2848 2848	119.9	90
l‘eSr-POPULATION-1	438 406 375	1797 1922 1937	2563 2781 2828	90.6	87
l‘eSr-POPULATION-2	457 457 429	1797 1937 1906	2563 2656 2714	121.3	219
l‘eSr-POPULATION-3	453 375 375	1891 2062 2000	2563 2688 2734	140.6	95
l‘eSr-POPULATION-4	484 453 375	1828 1953 1962	2578 2703 2797	109.4	91
l‘eSr-POPULATION-5	422 391 359	1875 2031 2016	2672 2844 2886	100.2	86
r'Ezr-PRESERVATION-1	516 484 422	1500 1531 1547	2314 2609 3078	45.2	109
r'Ezr-PRESERVATION-2	469 469 438	1578 1609 1594	2453 2672 2875	47.8	101
r'Ezr-PRESERVATION-3	453 438 406	1469 1516 1547	2276 2984 3016	46.8	116
r'Ezr-PRESERVATION-4	438 453 422	1531 1578 1578	2125 2410 2952	75.8	117
r'Ezr-PRESERVATION-5	419 469 438	1562 1562 1641	1984 2143 3156	65.3	98
t‘Ekr-PROTECTION-1	531 562 516	1766 1781 1812	2563 2500 2429	71.7	107
w‘izr-QUEASINESS-1	281 281 297	2109 2219 2141	2375 2547 2790	83.3	125
w‘izr-QUEASINESS-2	312 312 312	2047 2172 2094	2375 2656 2672	88.8	114
w‘izr-QUEASINESS-3	344 328 281	1687 2172 2172	2234 2500 2962	93.8	81
w‘izr-QUEASINESS-4	297 297 297	2203 2203 2187	2514 2719 2828	50.3	117
w‘izr-QUEASINESS-5	312 297 281	2062 2250 2219	2333 2476 2590	109.7	143
w‘Esr-QUESTION-1	524 531 362	1250 1500 1687	2248 2219 2314	100.1	138
w‘Esr-QUESTION-2	514 531 531	1125 1406 1594	2181 2238 2324	103.9	134
w‘Esr-QUESTION-3	484 562 562	1078 1344 1547	2187 2203 2281	122.2	118
w‘Esr-QUESTION-4	467 438 419	1581 1750 1867	2312 2438 2581	81.6	115
w‘Esr-QUESTION-5	656 638 0	1410 1581 1762	2281 2286 0	88.0	104
w'Esr-QUESTIONNAIRE-1	531 578 590	1125 1328 1594	2141 2141 2312	103.8	103
w'Esr-QUESTIONNAIRE-2	594 562 352	1469 1625 1771	2267 2324 0	89.9	120
w'Esr-QUESTIONNAIRE-3	562 524 469	1438 1594 1687	2219 2312 2390	83.4	110
w'Esr-QUESTIONNAIRE-4	524 562 505	1250 1448 1686	2156 2238 2390	92.5	89
w'Esr-QUESTIONNAIRE-5	495 562 400	1281 1448 1657	2171 2248 2486	105.5	119
r‘edr-RADIO-1	406 422 406	1859 2016 2109	2187 2422 2750	111.0	90
r‘edr-RADIO-2	438 438 422	1734 1875 1937	2172 2312 2438	103.6	89
r‘edr-RADIO-3	469 453 422	1750 1937 2000	2109 2469 2547	91.4	85
r‘edr-RADIO-4	391 375 344	1641 1812 1922	2162 2797 3063	123.8	119
r‘edr-RADIO-5	422 422 406	1719 1906 2016	2109 2248 2594	96.3	103
b‘Λtr-REBUTTAL-1	625 656 641	1172 1203 1281	2500 2547 2594	110.6	97
b‘Λtr-REBUTTAL-2	609 625 656	1141 1172 1219	2563 2641 2688	124.2	98
b‘Λtr-REBUTTAL-3	500 562 594	1109 1141 1234	2312 2422 2500	104.3	142
b‘Λtr-REBUTTAL-4	547 578 578	1109 1141 1312	2422 2486 2594	98.7	151
b‘Λtr-REBUTTAL-5	516 578 625	1125 1188 1297	2406 2484 2594	107.6	110
k‘Itr-SCHIZOID-1	375 406 391	2031 1969 1875	2813 2766 2734	51.3	137

k'Itr-SCHIZOID-2	344 406 406	2047 1969 1891	2625 2578 2672	49.3	148
k'Itr-SCHIZOID-3	391 422 406	2062 1969 1859	2625 2703 2578	46.9	150
k'Itr-SCHIZOID-4	344 359 344	1953 1891 1844	2672 2657 2609	52.1	174
k'Itr-SCHIZOID-5	359 375 359	2031 1937 1891	2625 2656 2672	46.5	128
k'Itr-SCHIZOPHRENIC-1	391 406 391	2047 1969 1875	2533 2600 2625	55.7	137
k'Itr-SCHIZOPHRENIC-2	359 406 406	1984 1953 1906	2533 2562 2590	55.6	154
k'Itr-SCHIZOPHRENIC-3	375 391 359	1984 1937 1812	2562 2571 2594	42.8	136
k'Itr-SCHIZOPHRENIC-4	375 391 375	1875 1812 1781	2547 2578 2625	43.7	124
k'Itr-SCHIZOPHRENIC-5	406 391 359	1891 1844 1750	2578 2641 2625	43.0	136
s'iwr-SEAWEED-1	281 281 281	2125 2172 2000	3141 2981 2305	88.0	98
s'iwr-SEAWEED-2	281 266 266	2156 2219 2234	3124 3067 2714	97.9	131
s'iwr-SEAWEED-3	297 281 281	2156 2203 2203	3109 3172 2695	103.0	111
s'iwr-SEAWEED-4	297 297 312	2094 2172 2062	2844 2844 2312	90.9	102
s'iwr-SEAWEED-5	266 281 281	2109 2109 1984	2781 2457 2229	68.5	103
w'idr-SEAWEED-1	328 344 344	1828 2141 2141	2266 2328 2484	87.1	87
w'idr-SEAWEED-2	266 250 250	2109 2266 2234	2343 2590 3010	95.6	119
w'idr-SEAWEED-3	297 312 328	2094 2266 2266	2328 2438 2610	130.5	91
w'idr-SEAWEED-4	344 344 328	1375 1594 1719	2297 2344 2328	79.7	92
w'idr-SEAWEED-5	266 266 297	1906 2219 2234	2234 2453 2686	109.4	92
s'Igr-SIGNATURES-1	391 391 406	2000 2109 2203	2688 2609 2578	72.2	105
s'Igr-SIGNATURES-2	422 422 390	2000 2141 2328	2766 2734 2734	68.5	108
s'Igr-SIGNATURES-3	422 406 438	1984 2141 2229	2656 2609 2516	74.1	107
s'Igr-SIGNATURES-4	422 422 438	2062 2203 2266	2672 2625 2563	70.2	100
s'Igr-SIGNATURES-5	391 381 390	2031 2086 2181	2705 2619 2505	64.3	96
g'Etr-SPAGHETTI-1	375 438 500	2125 2062 2000	2857 2656 2625	97.5	96
g'Etr-SPAGHETTI-2	406 438 469	2094 2062 2000	2563 2563 2594	82.5	107
g'Etr-SPAGHETTI-3	375 406 438	2125 2062 2000	2625 2594 2656	95.7	89
g'Etr-SPAGHETTI-4	375 438 469	2156 2094 2094	2969 2906 2844	102.5	84
g'Etr-SPAGHETTI-5	344 406 438	2187 2125 2062	2990 2875 2688	92.5	113
t'etr-STATEHOUSE-1	422 406 406	1922 2078 2156	2969 3078 2984	111.2	89
t'etr-STATEHOUSE-2	406 406 406	2047 2172 2219	2828 2886 2819	100.1	104
t'etr-STATEHOUSE-3	422 438 422	1953 2031 2047	2859 2922 2891	97.8	89
t'etr-STATEHOUSE-4	438 422 391	2000 2078 2109	2781 2813 2813	113.6	92
t'etr-STATEHOUSE-5	422 422 406	1984 2125 2172	2797 2819 2829	116.0	100
t'Idr-TIDBIT-1	359 359 328	1953 1937 1891	2922 2891 2813	36.5	118
t'Idr-TIDBIT-2	375 406 359	2031 1984 1984	2813 2750 2750	60.1	118
t'Idr-TIDBIT-3	344 359 359	2062 2062 2000	2886 2891 2859	31.3	123
t'Idr-TIDBIT-4	406 406 359	1969 1906 1875	2828 2734 2563	59.1	113
t'Idr-TIDBIT-5	324 406 438	2062 2016 1984	2859 2844 2813	43.7	128
b'Itr-TIDBIT-1	406 453 438	1906 1969 1937	2547 2672 2969	90.3	93
b'Itr-TIDBIT-2	422 438 438	1937 1937 1953	2547 2563 2625	81.2	112
b'Itr-TIDBIT-3	391 406 406	1937 1937 1922	2547 2672 2828	86.3	90
b'Itr-TIDBIT-4	406 422 391	1875 1906 1859	2672 2844 2875	86.6	97
b'Itr-TIDBIT-5	391 375 344	1781 1844 1828	2453 2781 2828	45.0	188
r'izr-UNREASONABLE-1	390 390 390	2094 2109 2016	3000 3047 2969	89.2	99
r'izr-UNREASONABLE-2	375 375 359	2047 2109 2094	2813 2984 3016	109.7	98
r'izr-UNREASONABLE-3	359 328 328	2000 2078 2078	2453 3078 3031	95.6	90
r'izr-UNREASONABLE-4	328 312 297	2000 2094 2141	2312 2828 3000	96.9	114
r'izr-UNREASONABLE-5	359 328 297	1969 2062 2031	3019 3141 3016	103.3	96
w'Izr-VENTRILOQUISM-1	406 438 422	1078 1312 1609	2250 2266 2547	88.2	96
w'Izr-VENTRILOQUISM-2	422 422 375	1281 1547 1609	2250 2422 2641	83.0	104
w'Izr-VENTRILOQUISM-3	391 422 391	1109 1438 1672	2219 2250 2531	99.0	118
w'Izr-VENTRILOQUISM-4	422 438 422	1141 1375 1547	2156 2203 2500	91.6	99
w'Izr-VENTRILOQUISM-5	453 438 406	1344 1516 1578	2094 2234 2516	97.4	95

b'etr-VERBATIM-1	422 406 391	2016 2125 2187	2672 2790 2857	130.6	91
b'etr-VERBATIM-2	422 422 406	1891 1984 2078	2516 2641 2609	110.2	106
b'etr-VERBATIM-3	422 406 406	1953 2078 2094	2813 2906 2953	127.7	85
b'etr-VERBATIM-4	422 406 391	1969 2078 2156	2813 2969 2969	141.9	82
b'etr-VERBATIM-5	422 406 422	1953 2125 2109	2656 2938 2867	143.5	90
d'Als-ADULTERATED-1	562 594 578	1422 1281 1219	2686 2719 2797	90.2	103
d'Als-ADULTERATED-2	500 594 578	1516 1250 1156	2648 2641 2734	61.6	106
r'ets-ADULTERATED-1	406 391 375	1703 1859 1922	2190 2469 2609	90.4	97
r'ets-ADULTERATED-2	406 438 438	1719 1781 1828	2162 2344 2422	73.1	100
g'ets-ALLIGATOR-1	375 391 438	2047 1984 1937	2733 2686 2667	52.6	96
g'ets-ALLIGATOR-2	359 391 438	2047 2016 1953	3048 2790 2609	61.5	92
g'ets-ALLIGATOR-3	359 375 453	2047 2016 1906	2867 2859 2766	124.7	95
b'Ets-ALPHABET-1	500 484 484	1500 1625 1687	2359 2438 2484	80.3	99
b'Ets-ALPHABET-2	531 547 562	1641 1687 1750	2467 2531 2563	72.1	89
b'Ets-ALPHABETICAL-1	484 562 562	1594 1609 1609	2453 2619 2838	87.4	93
b'Ets-ALPHABETICAL-2	547 594 578	1500 1533 1552	2422 2516 2531	77.8	89
l'Ets-ATHLETIC-1	531 531 484	1297 1375 1422	2734 2703 2641	60.8	120
l'Ets-ATHLETIC-2	484 516 547	1203 1344 1422	2625 2656 2625	83.1	96
b'Its-BITTERSWEET-1	438 469 469	1875 1828 1781	2656 2625 2590	56.2	101
b'Its-BITTERSWEET-2	406 422 391	1781 1781 1766	2438 2484 2495	46.9	103
w'its-BITTERSWEET-1	250 250 234	2010 2143 2181	2352 2495 2552	56.7	82
w'its-BITTERSWEET-2	362 352 305	1906 2109 2172	2210 2400 2810	76.3	104
d'ids-CANDIED-1	352 314 286	2125 2109 2047	2705 3000 2895	48.0	95
s'Els-CELEBRATE-1	500 547 516	1516 1375 1266	2781 2719 2766	89.0	95
r'ets-CELEBRATE-1	484 469 438	1781 1937 2016	2219 2344 2594	148.3	92
s'Els-CELEBRATION-1	547 594 578	1359 1281 1172	2828 2813 2828	76.0	106
r'eSs-CELEBRATION-1	500 484 453	1531 1672 1781	2234 2375 2672	114.8	95
s'ils-CONCEAL-1	375 422 453	1906 1766 1594	2516 2484 2484	75.9	95
r'Its-CRITICISM-1	422 469 453	1500 1516 1543	1891 1953 2048	65.5	126
s'Izs-CRITICISM-1	422 422 406	1594 1594 1547	2734 2750 2750	89.6	107
r'Ass-CRUSTACEAN-1	514 495 476	1406 1500 1514	2125 2375 2531	74.9	91
r'Ass-CRUSTACEAN-2	469 531 531	1391 1438 1476	1906 2062 2219	75.8	108
r'Ass-CRUSTACEAN-3	467 457 419	1562 1610 1648	2219 2362 2495	57.8	97
r'Ass-CRUSTACEAN-4	547 531 438	1422 1484 1594	2000 2187 2381	77.9	104
t'eSs-CRUSTACEAN-1	422 375 375	1922 2016 2031	2813 3344 2766	132.5	96
t'eSs-CRUSTACEAN-2	422 359 344	1953 2109 2141	2922 3203 3248	151.9	123
t'eSs-CRUSTACEAN-3	422 391 312	2016 2156 2187	2875 2914 2886	134.3	110
t'eSs-CRUSTACEAN-4	406 391 375	1984 2062 2067	2829 2857 2813	112.7	99
k'Ass-CUSTOMARILY-1	543 547 78	1562 1578 1625	2563 2688 2719	56.9	109
d'Els-DELTA-1	516 562 594	1687 1469 1250	2688 2656 2656	103.1	103
d'Ets-DETRIMENTAL-1	453 484 500	1766 1703 1672	2719 2719 2734	77.5	112
b'Ass-FILIBUSTER-1	578 594 600	1266 1375 1486	2533 2600 2656	109.4	84
g'izs-FOGEYS-1	344 344 344	2062 2000 1906	2594 2672 2625	75.5	92
r'Ass-FRUSTRATING-1	531 562 578	1281 1359 1406	1922 2125 2328	74.9	101
r'ets-FRUSTRATING-1	438 469 467	1687 1781 1875	2281 2531 2594	110.6	95
w'Azs-FUZZY-WUZZY-1	484 516 438	1234 1484 1641	2266 2359 2781	160.0	95
w'Azs-FUZZY-WUZZY-2	547 562 484	1328 1453 1562	2375 2609 2848	126.3	101
w'Azs-FUZZY-WUZZY-3	547 547 500	1250 1406 1547	2391 2516 2714	97.6	105
w'Azs-FUZZY-WUZZY-4	562 625 500	1188 1391 1578	2391 2547 2476	162.5	137
w'Azs-FUZZY-WUZZY-5	453 438 438	1281 1438 1578	2141 2297 2547	103.1	116
g'ets-GATOR-1	328 359 406	2109 2109 1937	3286 3267 2819	155.8	140
g'ets-GATOR-2	391 391 422	1984 2016 1984	2943 2962 2771	105.2	137
g'ets-GATOR-3	375 406 422	2031 2047 2031	3203 3141 2933	113.8	111
g'ets-GATOR-4	328 359 422	2078 2109 2031	3200 3124 2895	137.6	115

g'ets-GATOR-5	375 391 375	2125 2125 2078	2922 2938 2828	121.3	101
g'izs-GEEZERS-1	297 305 281	2156 2172 2094	3219 3141 2875	148.2	96
r'Eds-INCREDIBLY-1	547 609 609	1578 1562 1578	2219 2328 2391	101.2	154
r'Eds-INCREDIBLY-2	594 641 625	1656 1625 1625	2295 2453 2453	75.7	167
d'iss-INDECENTLY-1	281 234 297	2172 2172 2187	3234 3281 3172	112.3	120
d'iss-INDECENTLY-2	297 281 297	2109 2187 2125	3172 3250 3048	149.4	122
d'Λss-INDUSTRIALIST-1	429 438 438	1656 1547 1484	2797 2781 2859	110.7	116
d'Λss-INDUSTRIALIST-2	547 578 578	1609 1500 1484	2750 2766 2875	94.6	107
d'Λss-INDUSTRIALIZATION-1	484 547 500	1625 1531 1516	2766 2797 2943	105.0	110
z'eSs-INDUSTRIALIZATION-1	391 391 375	1859 1922 1953	2743 2703 2719	139.5	101
w'Izs-INQUISITIVE-1	391 375 344	1547 1734 1797	2248 2391 2676	65.3	121
w'Izs-INQUISITIVE-2	359 359 344	1625 1656 1625	2219 2281 2578	54.6	137
s'Λls-INSULT-1	500 562 516	1422 1257 1095	2844 2859 3016	117.9	86
s'Λls-INSULT-2	531 578 562	1250 1156 1047	2797 2797 2953	112.1	76
t'Egs-INTEGRITY-1	476 406 390	1766 1914 2029	2743 2705 2629	97.5	82
l'izs-ISOSCELES-1	391 359 359	1766 1906 2000	2641 2688 2781	88.7	103
l'izs-ISOSCELES-2	422 438 406	1594 1781 1844	2656 2734 2781	109.0	90
l'izs-ISOSCELES-3	375 344 276	1687 1984 2094	2625 2703 2875	113.8	94
J'ews-JAYWALKING-1	438 514 533	1937 2016 2078	2844 2797 2467	115.2	168
J'ews-JAYWALKING-2	391 406 391	2016 2062 2047	2844 2797 2314	91.5	112
l'Its-LITERATURE-1	438 484 484	1375 1562 1609	2609 2641 2641	67.9	105
l'EJs-LEGISLATOR-1	484 484 484	1438 1547 1625	2672 2688 2734	75.5	113
l'EJs-LEGISLATOR-2	516 531 500	1359 1484 1609	2750 2750 2734	81.8	134
l'EJs-LEGISLATOR-3	500 531 484	1484 1625 1734	2672 2734 2859	95.9	113
l'EJs-LEGISLATOR-4	516 516 469	1469 1594 1703	2672 2703 2766	74.0	108
l'EJs-LEGISLATOR-5	516 531 531	1484 1641 1672	2969 2943 2905	78.3	92
l'ets-LEGISLATOR-1	469 453 438	1625 1859 1906	2625 2688 2656	124.1	94
l'ets-LEGISLATOR-2	484 484 469	1547 1703 1828	2547 2547 2594	65.3	127
l'ets-LEGISLATOR-3	500 453 406	1562 1922 1984	2484 2819 2905	159.3	95
l'ets-LEGISLATOR-4	484 469 453	1609 1687 1734	2719 2828 2859	78.4	102
l'ets-LEGISLATOR-5	453 469 438	1547 1781 1859	2688 2766 2886	105.4	91
l'eSs-POPULATION-1	438 422 375	1922 2000 2016	2656 2734 2781	123.9	92
r'Ezs-PRESERVATION-1	500 469 94	1562 1562 1578	2797 2938 2969	90.0	96
w'Ess-QUESTION-1	562 562 495	1469 1547 1641	2187 2219 2281	96.6	87
r'eds-RADIO-1	438 422 422	1812 1859 1937	2312 2406 2531	75.7	90
r'eds-RADIO-2	422 438 406	1766 1875 1969	2078 2359 2486	90.2	92
k'Its-SCHIZOID-1	359 422 406	2031 2000 1953	2733 2719 2781	61.1	110
k'Its-SCHIZOID-2	359 359 359	2078 2078 2000	2771 2828 2828	74.6	118
s'iws-SEAWEED-1	312 297 328	1937 2031 2016	3141 3203 2505	123.7	132
s'iws-SEAWEED-2	297 281 281	2062 2125 2203	3078 3203 2875	105.2	125
w'ids-SEAWEED-1	297 297 297	1990 2109 2109	2210 2734 2981	111.0	90
w'ids-SEAWEED-2	297 281 297	2187 2219 2152	2422 2505 2419	180.9	89
g'Ets-SPAGHETTI-1	344 375 438	2094 2047 2000	3095 2981 2547	106.5	94
g'Ets-SPAGHETTI-2	500 516 484	1906 1891 1875	2844 2797 2797	64.3	160
t'ets-STATEHOUSE-1	438 422 422	1828 1906 1969	2750 2891 3016	97.0	94
t'Ids-TIDBIT-1	419 406 375	1984 1953 1937	2781 2734 2813	73.7	139
b'Its-TIDBIT-1	390 381 352	1859 1906 1859	2581 2719 2766	128.9	123
b'ets-VERBATIM-1	469 453 406	1844 1953 2031	2547 2813 3000	164.4	105

C.2 Speaker RU (Female)

Label	F1 (Hz)	F2 (Hz)	F3 (Hz)	Du. (ms)	F0 (Hz)
b'Izc-ABYSMAL-1	406 422 391	2000 2000 1844	3063 3047 3047	85.0	229
d'etc-ACCOMMODATED-1	500 500 484	2219 2297 2312	3047 3063 3078	91.0	168
l'etc-ACCUMULATED-1	578 578 516	1812 2109 2203	3016 3000 3047	106.0	167
d'Λlc-ADULTERATED-1	578 609 609	1422 1250 1172	3125 3016 3047	66.1	193
r'etc-ADULTERATED-1	500 516 484	1906 2141 2219	2875 2938 3000	94.6	167
g'etc-ALLIGATOR-1	516 500 531	2524 2486 2359	3000 3047 3078	132.2	172
b'Etc-ALPHABET-1	641 625 609	1844 1953 1937	3031 3031 3000	94.4	162
b'Etc-ALPHABETICAL-1	578 625 594	1562 1734 1781	2953 3000 2984	79.1	195
w'etc-ANTIQUATED-1	469 484 484	1781 2156 2234	2828 2875 2969	61.4	168
t'Ekc-ARCHITECTURE-1	625 656 641	1969 1953 1937	2922 2891 2844	69.3	170
r'Isc-ARISTOCRATIC-1	391 438 469	1359 1562 1672	1781 1952 2067	40.5	184
l'Etc-ATHLETIC-1	594 609 641	1422 1687 1750	3281 3141 3109	70.4	208
z'elc-AZALEA-1	516 578 625	2094 2094 1797	3047 2953 2969	126.6	198
b'Itc-BITTERSWEET-1	469 484 438	1969 1969 2000	2984 3016 2984	52.9	203
w'itc-BITTERSWEET-1	375 391 391	2156 2406 2375	2859 2922 2984	69.7	165
d'idc-CANDIED-1	375 375 391	2406 2453 2484	3094 3109 3094	93.3	163
s'Elc-CELEBRATION-1	578 594 562	1469 1422 1359	3078 3047 3031	53.4	182
r'eSc-CELEBRATION-1	562 469 422	2125 2266 2297	3000 2969 2984	105.4	205
l'esc-COMPLACENT-1	594 578 438	1594 2031 2250	3094 3031 3094	106.6	208
s'ilc-CONCEAL-1	359 391 438	2484 2563 2109	3063 3047 3057	158.5	216
d'ISc-CONDITION-1	438 453 484	2114 2141 1984	3063 3000 3031	91.5	242
r'Itc-CRITICISM-1	453 469 469	1687 1844 1891	2181 2533 2688	53.4	213
s'Izc-CRITICISM-1	375 375 359	1891 1875 1828	3141 3125 3125	70.1	158
r'Λsc-CRUSTACEAN-1	484 484 400	1800 1867 1924	2891 2875 2895	41.9	181
t'eSc-CRUSTACEAN-1	578 531 453	2281 2400 2375	3031 3047 3031	120.7	211
k'Λsc-CUSTOMARILY-1	531 562 531	1750 1734 1724	3016 3016 3031	36.9	193
d'ikc-DECREASE-1	359 328 312	2610 2625 2695	3125 3063 3029	97.7	232
r'isc-DECREASE-1	406 391 328	2000 2281 2375	2486 2875 3016	89.7	163
d'Elc-DELTA-1	594 688 672	1719 1500 1312	3063 3063 3000	87.5	180
d'Etc-DETRIMENT-1	562 578 562	1953 1953 1937	3094 3063 3094	80.0	186
d'Etc-DETRIMENTAL-1	531 516 484	1937 1937 1937	3109 3109 3078	63.9	178
d'Ilc-DILIGENTLY-1	484 531 500	1750 1594 1438	3172 3203 3171	63.7	208
d'Isc-DISCIPLINE-1	422 422 422	1844 1810 1734	3141 3141 3188	75.3	232
d'Isc-DISOBEDIENCE-1	422 453 469	1937 1953 1953	3125 3141 3141	49.9	198
b'idc-DISOBEDIENCE-1	391 391 344	2547 2571 2453	3063 3105 3031	143.8	229
w'edc-DISSUADED-1	562 578 531	1422 1937 2362	2922 2938 2984	128.3	200
b'etc-EXACERBATED-1	516 484 484	2125 2219 2234	2969 2969 3016	111.0	172
t'igc-FATIGUE-1	406 391 375	2578 2547 2531	3172 3078 2891	90.6	232
b'Λsc-FILIBUSTER-1	625 656 641	1234 1312 1422	2906 2906 2938	89.0	163
g'izc-FOGEYS-1	359 344 359	2781 2838 2516	3057 3105 3114	156.2	178
r'Λsc-FRUSTRATING-1	625 625 531	1531 1609 1703	2210 2276 2390	50.9	219
r'etc-FRUSTRATING-1	547 500 469	1719 2078 2187	2343 2533 2859	98.4	174
w'Λzc-FUZZY-WUZZY-1	547 562 562	1250 1531 1703	2875 2938 3063	91.4	190
g'etc-GATOR-1	531 547 516	2578 2514 2438	3094 3105 3125	152.5	190
g'izc-GEEZERS-1	359 328 328	2766 2703 2531	3266 3172 3219	121.0	225
g'Λtc-GUTTURAL-1	578 609 578	1703 1531 1609	3078 3109 3109	95.0	193
l'Λsc-ILLUSTRIOUS-1	562 578 594	1312 1344 1500	3156 3109 3078	79.4	195
r'Edc-INCREDIBLY-1	609 625 625	1625 1734 1750	2229 2371 2886	64.1	216
d'isc-INDECENTLY-1	391 391 391	2484 2469 2422	3109 3078 3125	88.5	208
d'Λsc-INDUSTRIAL-1	578 641 594	1625 1500 1562	3078 3047 3078	97.4	200

d'Asc-INDUSTRIALIZATION-1	562 578 562	1734 1703 1703	3094 3078 3078	79.4	190
z'eSc-INDUSTRIALIZATION-1	578 578 500	2141 2187 2312	2984 2984 2984	141.0	198
w'Izc-INQUISITIVE-1	500 484 469	1828 1875 1844	2875 2969 3063	41.9	258
s'Alc-INSULT-1	578 562 609	1281 1203 1156	3031 2969 2906	60.0	178
t'Egc-INTEGRITY-1	578 594 547	2031 2062 2229	2984 2969 2867	74.9	188
l'izc-ISOSCELES-1	453 422 375	1766 2078 2312	3047 3078 3047	70.5	162
J'ewc-JAYWALKING-1	516 562 531	2172 2344 2031	2969 2969 2938	128.6	195
d'ezc-LACKADAISICAL-1	531 547 516	2238 2343 2219	3016 3031 3047	131.6	190
l'EJc-LEGISLATOR-1	531 562 547	1625 1812 1906	3188 3172 3188	76.6	184
l'etc-LEGISLATOR-1	516 484 484	1750 2000 2062	3094 3094 3078	78.8	172
l'Itc-LITERATURE-1	453 453 438	1641 1750 1812	3047 3063 3094	59.5	216
l'Itc-LITIGATION-1	484 547 547	1406 1656 1703	3172 3125 3109	41.8	190
g'eSc-LITIGATION-1	562 547 453	2469 2495 2429	3063 3047 3095	143.6	203
b'idc-LOBBIED-1	391 375 344	2141 2375 2422	2906 3047 3109	85.6	182
l'itc-OBSOLETE-1	406 375 391	2406 2469 2422	3078 3063 3047	103.3	219
l'eSc-POPULATION-1	531 547 531	1781 2078 2203	3125 3109 3016	117.0	186
r'Ezc-PRESERVATION-1	547 547 516	1766 1812 1844	3016 3094 3109	30.9	186
t'Ekc-PROTECTION-1	641 656 625	1922 1969 1937	2797 2743 2750	74.3	219
w'izc-QUEASINESS-1	391 359 297	2484 2547 2406	2891 3031 3063	82.0	219
w'Esc-QUESTION-1	609 609 609	1578 1797 1906	2688 2813 2906	57.4	208
w'Esc-QUESTIONNAIRE-1	562 547 516	1453 1656 1891	2828 2969 3109	65.6	188
r'edc-RADIO-1	547 562 438	2062 2328 2438	2813 2969 3047	112.8	203
b'Atc-REBUTTAL-1	578 594 609	1344 1328 1391	2859 2906 2953	92.5	198
k'Itc-SCHIZOID-1	484 484 500	2203 2141 1984	2875 2922 2938	47.9	254
k'Itc-SCHIZOPHRENIC-1	438 453 453	2016 1937 1891	2969 2969 3000	37.5	190
s'iwc-SEAWEED-1	328 297 312	2563 2625 2281	3047 3031 2813	99.8	235
w'idc-SEAWEED-1	391 375 359	1812 2543 2469	2797 2924 3063	106.2	190
s'Igc-SIGNATURES-1	438 406 391	1953 1969 1953	2938 2891 2844	40.5	219
g'Etc-SPAGHETTI-1	547 594 625	2328 2187 2109	3125 3031 3000	111.5	205
t'etc-STATEHOUSE-1	578 578 547	2281 2359 2375	3078 3063 3047	100.5	198
t'Idc-TIDBIT-1	438 422 422	2125 2156 2187	3094 3078 3078	29.2	178
b'Itc-TIDBIT-1	406 453 453	1922 2031 2094	2859 2922 3031	67.6	184
r'izc-UNREASONABLE-1	391 375 391	2250 2297 2187	3000 3125 3156	86.6	213
w'Izc-VENTRILOQUISM-1	516 500 453	1375 1562 1812	2891 3016 3016	66.4	174
b'etc-VERBATIM-1	562 562 578	2062 2156 2141	2984 3094 3125	119.8	193
b'Izr-ABYSMAL-1	422 391 344	1969 1969 1906	3000 3143 3219	90.6	178
d'etr-ACCOMMODATED-1	594 600 547	2406 2514 2486	3076 3124 3105	124.8	158
l'etr-ACCUMULATED-1	578 581 543	1812 2133 2200	2938 2906 2938	84.0	184
d'Alr-ADULTERATED-1	625 641 641	1438 1328 1172	3250 3172 3234	60.1	174
r'etr-ADULTERATED-1	484 484 484	1969 2062 2172	2781 2859 2750	87.3	172
g'etr-ALLIGATOR-1	500 581 590	2486 2467 2391	2971 3019 2969	108.9	167
b'Etr-ALPHABET-1	594 672 625	1734 1891 1984	2891 2938 3031	108.0	167
b'Etr-ALPHABETICAL-1	619 638 625	1453 1547 1800	2906 2984 3016	67.7	170
w'etr-ANTIQUATED-1	610 562 562	1641 2000 2248	2766 2875 2938	72.9	168
t'Ekr-ARCHITECTURE-1	641 641 562	2187 2203 2210	2875 2828 2828	66.9	168
r'Isr-ARISTOCRATIC-1	438 469 516	1714 1829 1906	2125 2703 2838	44.5	182
l'Etr-ATHLETIC-1	625 641 688	1297 1533 1766	3152 3094 3047	86.2	213
z'elr-AZALEA-1	531 562 600	1924 1867 1750	3000 3000 3000	69.4	174
b'Itr-BITTERSWEET-1	484 500 469	2010 2010 1984	2800 2829 2750	46.0	190
w'itr-BITTERSWEET-1	359 422 422	1844 2266 2600	2734 2867 3029	95.4	172
d'idr-CANDIED-1	344 359 359	2250 2219 2219	2813 2829 2857	58.2	172
s'Elr-CELEBRATION-1	610 648 609	1531 1419 1312	2953 2922 2938	81.9	193
r'eSr-CELEBRATION-1	547 500 438	1703 2141 2172	2172 2813 2859	92.4	180
l'esr-COMPLACENT-1	590 524 500	1838 2078 2219	3029 3047 3000	110.2	180

s‘ilr-CONCEAL-1	359 406 500	2375 2438 1969	2938 2844 2906	118.3	193
d‘ISr-CONDITION-1	438 453 438	2141 2141 2141	2953 2969 3000	83.9	178
r‘Itr-CRITICISM-1	453 453 453	1619 1676 1705	2171 2190 2210	37.5	246
s’Izr-CRITICISM-1	453 422 375	1906 1891 1781	3031 3047 3172	88.1	186
r’Λsr-CRUSTACEAN-1	328 438 453	1906 1922 2016	2578 2828 2938	35.3	0
t‘eSr-CRUSTACEAN-1	500 516 453	2156 2312 2422	3094 3031 3047	102.7	172
k’Λsr-CUSTOMARILY-1	676 667 610	1500 1562 1695	2819 2938 3172	66.0	216
d‘ikr-DECREASE-1	344 344 344	2531 2578 2563	3141 3078 3016	69.3	178
r’isr-DECREASE-1	406 359 359	2016 2352 2422	2422 2705 2953	89.4	178
d‘Elr-DELTA-1	667 672 667	1734 1438 1359	3141 3188 3266	97.9	176
d‘Etr-DETRIMENT-1	578 656 600	2000 2000 2029	3156 3109 3094	76.2	178
d’Etr-DETRIMENTAL-1	638 657 629	2031 2016 2047	3234 3219 3266	79.3	167
d‘Ilr-DILIGENTLY-1	516 547 547	1547 1406 1343	3125 3094 3203	58.0	203
d‘Isr-DISCIPLINE-1	453 469 453	1906 1891 1891	3078 3109 3200	53.3	168
d’Isr-DISOBEDIENCE-1	438 422 359	2031 1962 1953	3141 3188 3210	54.1	174
b‘idr-DISOBEDIENCE-1	359 359 375	2438 2533 2500	3016 3063 3094	97.8	174
w‘edr-DISSUADED-1	562 571 543	1438 2078 2234	2734 2766 2813	122.9	174
b’etr-EXACERBATED-1	590 594 578	2095 2314 2410	2734 2971 3029	125.7	158
t‘igr-FATIGUE-1	359 359 391	2381 2400 2362	3250 3203 2922	137.5	225
b’Λsr-FILIBUSTER-1	609 641 656	1156 1266 1406	3016 2969 2938	77.0	158
g’izr-FOGEYS-1	375 391 406	2476 2484 2400	2800 2876 3019	135.4	225
r‘Λsr-FRUSTRATING-1	629 641 629	1391 1406 1438	2000 2067 2048	77.0	178
r’etr-FRUSTRATING-1	571 594 547	1984 2133 2362	2762 2924 3047	116.3	165
w‘Λzr-FUZZY-WUZZY-1	641 610 486	1297 1484 1922	2771 3109 3067	128.9	160
g‘etr-GATOR-1	484 484 562	2516 2563 2531	3094 3125 3063	126.6	186
g‘izr-GEEZERS-1	328 344 328	2641 2672 2609	3031 3094 3143	117.0	170
g‘Λtr-GUTTURAL-1	629 676 672	1516 1453 1469	2781 2766 2829	95.4	178
l‘Λsr-ILLUSTRIOUS-1	600 672 657	1250 1375 1438	3406 3297 3266	94.5	180
r‘Edr-INCREDIBLY-1	609 648 619	1578 1714 1797	2171 2305 2667	62.9	193
d‘isr-INDECENTLY-1	375 343 312	2286 2229 2305	2971 2971 2971	97.3	219
d‘Λsr-INDUSTRIAL-1	609 625 657	1828 1703 1500	3172 3141 3109	62.4	163
d’Λsr-INDUSTRIALIZATION-1	600 629 619	1844 1781 1719	3109 3031 3076	75.0	184
z‘eSr-INDUSTRIALIZATION-1	594 547 453	2172 2448 2495	3063 3095 3076	134.2	216
w‘Izr-INQUISITIVE-1	422 422 344	1641 1867 1971	2857 2922 2924	72.4	232
s’Λlr-INSULT-1	648 688 656	1359 1266 1188	2844 2797 2828	81.7	174
t‘Egr-INTEGRITY-1	676 641 543	2016 2000 2016	2505 2524 2563	85.6	172
l’izr-ISOSCELES-1	422 406 375	1922 2078 2219	3031 3063 3063	75.4	154
J‘ewr-JAYWALKING-1	484 500 484	2344 2390 2375	2938 2922 2906	117.1	176
d‘ezr-LACKADAISICAL-1	500 484 484	2469 2484 2453	3109 3094 3063	119.3	172
l‘EJr-LEGISLATOR-1	600 610 600	1500 1734 1891	3156 3172 3172	72.8	190
l’etr-LEGISLATOR-1	562 533 516	1828 2094 2114	3047 3031 3031	88.4	176
l‘Itr-LITERATURE-1	531 552 562	1375 1453 1562	3203 3219 3141	36.5	193
l’Itr-LITIGATION-1	484 531 500	1516 1656 1766	3234 3125 3016	67.3	182
g‘eSr-LITIGATION-1	500 484 484	2344 2359 2391	2938 2922 2953	116.4	170
b’idr-LOBBIED-1	469 453 422	1922 2381 2391	2859 2971 3031	63.4	193
l‘itr-OBSOLETE-1	391 359 359	2162 2390 2457	3047 3063 3152	114.5	182
l‘eSr-POPULATION-1	609 578 543	1891 2297 2371	3141 3094 3047	95.3	155
r’Ezr-PRESERVATION-1	629 581 543	1781 1891 1933	2438 3038 3086	76.4	184
t‘Ekr-PROTECTION-1	688 672 641	2000 1953 1953	2641 2531 2547	65.8	165
w‘izr-QUEASINESS-1	391 391 375	2152 2257 2276	2766 2867 2943	77.5	208
w‘Esr-QUESTION-1	695 686 533	1516 1656 1857	2688 2766 2859	73.1	250
w’Esr-QUESTIONNAIRE-1	686 688 641	1600 1714 1875	2688 2719 2819	74.5	176
r‘edr-RADIO-1	516 524 469	1766 2281 2295	2295 2875 2922	98.8	176
b‘Λtr-REBUTTAL-1	656 734 648	1281 1297 1375	2734 2875 3016	121.3	163

k'Itr-SCHIZOID-1	422	422	391	2250	2114	2016	2891	2891	2891	38.5	188
k'Itr-SCHIZOPHRENIC-1	500	484	390	2125	2078	2029	2891	2953	3000	45.8	174
s'iwr-SEAWEED-1	390	362	371	2514	2562	2422	3094	3109	3000	112.2	213
w'idr-SEAWEED-1	453	453	453	2109	2419	2406	2859	2875	3000	106.4	155
s'Igr-SIGNATURES-1	484	469	344	2125	2109	2109	2875	2828	2875	48.9	186
g'Etr-SPAGHETTI-1	543	571	590	2324	2281	2266	2969	2953	3000	96.0	174
t'etr-STATEHOUSE-1	590	552	531	2314	2419	2333	3047	3031	3016	110.6	188
t'Idr-TIDBIT-1	438	438	295	2219	2172	2162	3016	3016	2953	44.9	193
b'Itr-TIDBIT-1	531	578	578	2109	2143	2156	2938	2953	3031	115.8	150
r'izr-UNREASONABLE-1	359	344	344	2406	2438	2391	3078	3141	3156	95.1	186
w'Izr-VENTRILOQUISM-1	516	500	484	1438	1656	1781	3016	3031	3078	65.1	172
b'etr-VERBATIM-1	581	516	524	2125	2344	2344	2891	3016	3031	143.2	172
d'Als-ADULTERATED-1	547	609	594	1500	1328	1172	3125	3109	3125	58.9	172
r'ets-ADULTERATED-1	516	516	469	2000	2047	2094	3422	2750	2859	80.2	168
g'ets-ALLIGATOR-1	500	547	516	2400	2359	2314	2906	2953	2969	86.6	186
b'Ets-ALPHABET-1	672	719	672	1687	1943	2000	2781	2905	3095	178.2	158
b'Ets-ALPHABETICAL-1	594	656	625	1500	1625	1656	2906	3000	3078	54.5	170
t'Eks-ARCHITECTURE-1	656	625	609	1922	1984	2019	3219	3266	3375	63.7	160
r'Iss-ARISTOCRATIC-1	422	484	438	1469	1562	1848	1812	1953	2750	44.6	193
l'Ets-ATHLETIC-1	594	609	625	1391	1609	1891	3297	3219	3203	99.5	203
z'els-AZALEA-1	562	672	703	1953	1922	1562	3016	2984	3094	64.8	182
b'Its-BITTERSWEET-1	406	438	406	1829	1969	2016	3162	2857	2813	50.9	184
w'its-BITTERSWEET-1	359	359	359	2187	2171	2162	2844	2813	2695	128.2	170
d'ids-CANDIED-1	375	375	359	2656	2672	2641	3156	3203	3203	94.6	182
s'Els-CELEBRATION-1	672	672	641	1590	1375	1328	3063	3078	3094	78.2	174
r'eSs-CELEBRATION-1	562	531	469	1895	2152	2400	2562	2875	2969	104.0	163
l'ess-COMPLACENT-1	562	547	484	1905	2124	2162	3016	3047	3016	109.8	188
r'Ass-CRUSTACEAN-1	359	484	438	1797	1937	1962	2724	2703	2734	31.0	178
t'eSs-CRUSTACEAN-1	531	516	484	2203	2312	2328	2969	2922	2953	104.0	178
d'Els-DELTA-1	625	625	625	1750	1562	1297	3250	3200	3200	101.8	162
d'Ets-DETRIMENTAL-1	578	594	547	2000	1969	2031	3141	3125	3094	64.5	168
d'Iss-DISCIPLINE-1	406	406	375	1750	1734	1703	2953	3000	2906	56.5	213
d'Iss-DISOBEDIENCE-1	359	391	391	1906	1859	1828	3109	3181	3238	42.5	168
b'ids-DISOBEDIENCE-1	359	359	359	2281	2457	2495	2859	2924	2981	91.8	176
t'igs-FATIGUE-1	448	453	391	2547	2453	2500	3190	3141	3047	337.5	186
b'Ass-FILIBUSTER-1	562	656	672	1203	1266	1375	3078	3094	3125	72.1	176
g'izs-FOGEYS-1	328	344	328	2719	2672	2656	2971	2943	2981	80.2	172
r'Ass-FRUSTRATING-1	594	672	656	1422	1500	1594	2267	2375	2448	74.5	176
r'ets-FRUSTRATING-1	516	594	562	1828	1905	1895	2406	2406	2375	126.2	163
w'Azs-FUZZY-WUZZY-1	578	609	594	1219	1422	1828	2688	2676	3094	120.0	200
g'ets-GATOR-1	531	547	531	2667	2594	2295	3105	3078	2971	117.0	193
g'izs-GEEZERS-1	328	328	344	2672	2688	2667	3234	3234	2914	138.4	205
g'Ats-GUTTURAL-1	590	609	578	1531	1469	1453	3105	2905	2762	66.1	165
d'Ass-INDUSTRIAL-1	547	562	581	1800	1703	1609	3152	3125	3095	61.4	177
d'Ass-INDUSTRIALIZATION-1	516	562	547	1734	1594	1516	2906	2813	2828	85.6	172
z'eSs-INDUSTRIALIZATION-1	500	500	469	2016	2187	2219	2844	2813	2828	141.1	165
w'Izs-INQUISITIVE-1	453	438	422	1625	1906	1937	2750	2859	3016	73.6	232
s'Als-INSULT-1	594	688	688	1375	1203	1125	3031	3000	3063	104.3	147
l'izs-ISOSCELES-1	406	422	422	1750	1984	2203	3078	3063	3031	89.7	155
J'ews-JAYWALKING-1	500	500	467	2109	2125	2109	2688	2703	2703	140.1	167
d'ezs-LACKADAISICAL-1	531	516	453	2266	2324	2172	3047	3125	3078	132.4	162
l'EJs-LEGISLATOR-1	578	594	609	1344	1734	1875	3156	3078	3031	104.2	195
l'ets-LEGISLATOR-1	609	600	571	1797	2016	2078	3000	2969	2922	158.1	178
l'Its-LITERATURE-1	406	531	516	1297	1448	1495	3248	3234	3234	44.4	184

l'Its-LITIGATION-1	484 469 469	1594 1719 1812	3344 3172 3031	54.7	170
g‘eSs-LITIGATION-1	500 469 438	2344 2297 2312	2828 2891 2859	94.2	157
l‘eSs-POPULATION-1	594 578 562	1953 2172 2203	3125 3016 3000	97.4	165
r'Ezs-PRESERVATION-1	600 581 533	1625 1875 1891	2438 3016 3078	80.1	172
t‘Eks-PROTECTION-1	641 672 619	1922 1906 1891	2734 2486 2469	66.1	184
w‘izs-QUEASINESS-1	406 359 344	2141 2328 2297	2766 2969 2984	88.0	178
w‘Ess-QUESTION-1	657 688 641	1486 1672 1844	2750 2703 2766	74.9	151
w'Ess-QUESTIONNAIRE-1	648 638 638	1469 1667 1766	2656 2734 2990	62.7	190
r‘eds-RADIO-1	562 484 453	1876 2109 2152	2229 2743 2703	101.2	178
b‘Ats-REBUTTAL-1	672 703 688	1250 1281 1391	2734 2953 3057	138.3	213
k‘Its-SCHIZOID-1	406 438 359	2141 2172 2078	2771 2895 2933	49.7	184
s‘iws-SEAWEED-1	359 359 344	2410 2371 2333	3031 3063 2984	131.1	176
w'ids-SEAWEED-1	406 406 422	2410 2429 2448	3000 3000 3016	295.5	168
s‘Igs-SIGNATURES-1	438 438 375	1906 1922 1875	2922 2969 2906	60.7	193
g‘Ets-SPAGHETTI-1	516 578 547	2076 2094 2109	3047 3031 3063	113.1	167
t‘ets-STATEHOUSE-1	562 562 578	2187 2152 2171	2766 2641 2656	152.4	193
t‘Ids-TIDBIT-1	453 500 484	2203 2181 2078	3078 3063 3047	51.1	190
b'Its-TIDBIT-1	516 516 516	2095 2086 2062	3016 3031 3078	117.9	178
r‘izs-UNREASONABLE-1	359 359 344	2219 2181 2171	2813 2969 3031	112.5	172
w'Izs-VENTRILOQUISM-1	484 484 469	1375 1578 1781	2984 3063 3125	65.4	167
b‘ets-VERBATIM-1	594 609 609	2125 2203 2172	2766 2734 2781	160.6	160

C.3 Speaker EE (Female)

Label	F1 (Hz)	F2 (Hz)	F3 (Hz)	Du. (ms)	F0 (Hz)
b‘Izc-ABYSMAL-1	391 375 375	1891 1891 1797	2750 2766 2766	91.8	193
d'etc-ACCOMMODATED-1	406 391 375	2359 2469 2453	2984 3031 3016	108.1	151
l'etc-ACCUMULATED-1	609 562 469	1578 1891 2312	3031 2984 2922	118.2	158
d‘Alc-ADULTERATED-1	453 500 438	1172 1125 1047	2688 2703 2750	101.7	188
r'etc-ADULTERATED-1	453 453 453	2124 2328 2406	2619 2750 2752	94.5	162
g'etc-ALLIGATOR-1	406 438 453	2547 2531 2391	2990 2922 2828	91.4	162
b'Etc-ALPHABET-1	547 562 562	1953 1984 2141	2766 2797 2876	132.3	151
b‘Etc-ALPHABETICAL-1	531 562 594	1797 1875 1906	2672 2688 2688	83.0	182
w'etc-ANTIQUATED-1	469 422 391	1500 1891 2141	2641 2656 2734	91.5	154
t'Ekc-ARCHITECTURE-1	457 469 484	2078 1937 1953	2594 2516 2359	60.9	182
r'Isc-ARISTOCRATIC-1	438 438 422	1594 1594 1687	2250 2328 2469	60.4	190
l‘Etc-ATHLETIC-1	500 516 531	1250 1484 1672	2609 2625 2609	81.1	186
z‘elc-AZALEA-1	484 500 500	1906 2078 1859	2672 2672 2453	172.2	186
b‘Itc-BITTERSWEET-1	391 422 438	1766 1797 1891	2563 2563 2563	54.8	195
w'itc-BITTERSWEET-1	312 312 297	2438 2667 2733	2875 2981 3124	126.3	157
d'idc-CANDIED-1	312 297 312	2703 2750 2703	3124 3200 3124	96.2	154
s'Elc-CELEBRATION-1	609 578 562	1619 1562 1266	2344 2344 2344	72.2	193
r‘eSc-CELEBRATION-1	500 484 469	1844 1875 1952	2229 2359 2448	101.0	180
l‘esc-COMPLACENT-1	516 438 375	1641 2295 2344	2750 2844 2848	111.2	195
s‘ilc-CONCEAL-1	375 375 375	2719 2766 2688	3125 3156 2984	142.5	200
d‘ISc-CONDITION-1	359 359 359	2114 2109 2062	2719 2781 2734	65.7	176
r‘Itc-CRITICISM-1	438 469 453	1812 1844 1844	2234 2344 2484	62.5	216
s'Izc-CRITICISM-1	344 391 344	1733 1781 1750	2719 2750 2752	48.9	162
r'Asc-CRUSTACEAN-1	516 469 410	1703 1734 1687	2190 2219 2362	58.1	184
t‘eSc-CRUSTACEAN-1	469 484 438	2219 2281 2359	2734 2766 2844	101.3	188

k'Λsc-CUSTOMARILY-1	625 641 328	1895 1886 1886	2562 2543 2562	64.3	213
d'ikc-DECREASE-1	344 359 328	2703 2781 1641	3234 3281 2766	87.7	193
r'isc-DECREASE-1	312 312 312	2391 2547 2609	2619 2969 2943	124.8	151
d'Elc-DELTA-1	500 562 578	1734 1672 1438	2734 2719 2641	69.6	195
d'Etc-DETRIMENT-1	516 531 500	1953 1953 1891	2734 2703 2672	87.2	182
d'Etc-DETRIMENTAL-1	438 500 469	1906 1781 1781	2734 2750 2656	68.5	203
d'Ilc-DILIGENTLY-1	422 469 453	1875 1656 1500	2797 2766 2781	76.2	193
d'Isc-DISCIPLINE-1	391 391 359	1781 1752 1724	2734 2703 2688	58.1	198
d'Isc-DISOBEDIENCE-1	359 359 391	1844 1844 1781	2762 2766 2714	61.5	188
b'idc-DISOBEDIENCE-1	359 359 359	2609 2641 2672	3016 3109 3109	81.0	182
w'edc-DISSUADED-1	484 422 359	1438 2266 2469	2641 2766 2859	128.5	182
b'etc-EXACERBATED-1	469 375 375	2109 2328 2422	2703 2838 2848	106.6	155
t'igc-FATIGUE-1	375 359 344	2943 3000 3038	3752 3790 3848	146.7	186
b'Λsc-FILIBUSTER-1	594 625 641	1484 1562 1594	2563 2547 2594	87.8	163
g'izc-FOGEYS-1	344 328 344	2714 2762 2734	3229 3295 3200	180.9	174
r'Λsc-FRUSTRATING-1	625 609 610	1312 1359 1457	1906 2067 2297	73.9	211
r'etc-FRUSTRATING-1	438 469 453	1891 2062 2172	2359 2469 2578	100.0	162
w'Λzc-FUZZY-WUZZY-1	484 516 469	1297 1672 1750	2828 2906 2938	127.1	182
g'etc-GATOR-1	391 406 359	2578 2578 2578	3063 3000 2953	113.8	176
g'izc-GEEZERS-1	312 344 359	2719 2752 2563	3352 3188 3125	143.1	193
g'Λtc-GUTTURAL-1	578 578 562	1859 1844 1734	2531 2500 2469	83.1	193
l'Λsc-ILLUSTRIOUS-1	562 562 562	1469 1571 1687	2938 2828 2688	81.1	193
r'Edc-INCREDIBLY-1	638 594 578	1687 1734 1672	2219 2276 2328	53.5	211
d'isc-INDECENTLY-1	312 344 344	2578 2625 2563	3109 3141 3095	67.6	200
d'Λsc-INDUSTRIAL-1	516 562 531	1875 1797 1781	2766 2734 2719	82.7	200
d'Λsc-INDUSTRIALIZATION-1	531 531 516	1719 1672 1703	2578 2484 2500	94.2	193
z'eSc-INDUSTRIALIZATION-1	484 484 453	1906 2203 2406	2766 2844 2859	122.2	174
w'Izc-INQUISITIVE-1	391 391 375	1625 1672 1859	2625 2594 2563	71.9	200
s'Λlc-INSULT-1	500 500 547	1172 1063 1047	2524 2438 2438	54.0	168
t'Egc-INTEGRITY-1	200 359 500	2076 2076 2156	2656 2625 2609	78.2	219
l'izc-ISOSCELES-1	312 312 312	2516 2648 2619	3031 3086 3109	164.0	147
J'ewc-JAYWALKING-1	406 500 469	2297 2297 1844	2656 2609 2594	131.0	188
d'ezc-LACKADAISICAL-1	375 375 375	2391 2391 2172	2953 2953 2875	116.1	184
l'EJc-LEGISLATOR-1	406 469 438	1453 1781 1812	2813 2750 2781	89.2	198
l'etc-LEGISLATOR-1	484 391 375	1500 1812 2109	2766 2781 2750	104.4	157
l'Itc-LITERATURE-1	469 500 500	1516 1547 1687	2703 2641 2578	64.1	193
l'Itc-LITIGATION-1	422 469 469	1469 1687 1703	2813 2797 2766	45.3	190
g'eSc-LITIGATION-1	391 391 375	2500 2516 2547	2969 2906 2800	121.1	178
b'idc-LOBBIED-1	328 328 312	2781 2797 2828	3250 3495 3594	111.7	162
l'itc-OBSOLETE-1	359 359 344	2578 2781 2766	2906 3250 3229	86.2	184
l'eSc-POPULATION-1	500 469 391	1984 2141 2266	2922 2969 3000	94.0	184
r'Ezc-PRESERVATION-1	516 422 344	1829 1781 1719	2500 2578 2594	64.0	182
t'Ekc-PROTECTION-1	600 578 516	1859 1859 1922	2516 2391 2328	61.0	203
w'izc-QUEASINESS-1	297 266 250	2453 2672 2484	2766 3067 3029	87.4	225
w'Esc-QUESTION-1	609 578 516	1281 1578 1734	2359 2406 2531	76.3	198
w'Esc-QUESTIONNAIRE-1	484 486 467	1438 1750 1781	2547 2656 2667	68.7	203
r'edc-RADIO-1	453 375 375	2375 2453 2547	2813 2953 3063	95.8	182
b'Λtc-REBUTTAL-1	609 656 641	1297 1312 1344	2484 2500 2547	96.8	167
k'Itc-SCHIZOID-1	406 406 406	2343 2281 2187	2724 2750 2719	42.8	213
k'Itc-SCHIZOPHRENIC-1	406 406 406	2219 2094 1969	2672 2609 2578	39.3	219
s'iwc-SEAWEED-1	375 359 359	2688 2797 2762	3109 3188 3016	94.5	193
w'idc-SEAWEED-1	297 297 297	2766 2867 2781	3047 3295 3229	125.8	151
s'Igc-SIGNATURES-1	391 438 406	1937 2000 2000	2672 2672 2609	44.5	216
g'Etc-SPAGHETTI-1	422 500 500	2516 2391 2375	3031 2922 2790	104.4	180

t'etc-STATEHOUSE-1	406 422 391	2359 2469 2531	2781 2906 2922	106.7	184
t'Idc-TIDBIT-1	406 438 406	2057 1990 1937	2875 2891 2859	48.9	235
b'Itc-TIDBIT-1	453 453 422	2234 2281 2234	2844 2969 2922	118.8	163
r'izc-UNREASONABLE-1	359 359 375	2141 2281 2266	2516 2781 2703	103.5	190
w'Izc-VENTRILOQUISM-1	438 453 391	1359 1656 1719	2594 2656 2688	72.9	165
b'etc-VERBATIM-1	500 484 391	2187 2359 2469	2734 2953 2953	133.7	174
b'Izr-ABYSMAL-1	406 391 359	1781 1781 1672	2719 2781 2781	87.0	182
d'etr-ACCOMMODATED-1	448 422 406	2312 2391 2359	2875 2953 2906	111.4	147
l'etr-ACCUMULATED-1	547 547 531	1781 2000 2125	2859 2859 2813	92.5	200
d'Alr-ADULTERATED-1	484 516 500	1422 1234 1094	2547 2563 2609	79.2	184
r'etr-ADULTERATED-1	484 469 469	2000 2234 2297	2344 2505 2703	85.3	165
g'etr-ALLIGATOR-1	406 453 469	2410 2312 2219	2875 2875 2656	80.7	163
b'Etr-ALPHABET-1	578 562 500	1766 1937 2124	2500 2547 2571	112.6	163
b'Etr-ALPHABETICAL-1	516 562 609	1687 1766 1734	2406 2406 2406	72.3	165
w'etr-ANTIQUATED-1	500 500 484	1359 1750 2125	2453 2453 2609	87.9	170
t'Ekr-ARCHITECTURE-1	547 562 531	1969 1891 1922	2562 2381 2266	79.2	198
r'Isr-ARISTOCRATIC-1	406 422 375	1641 1703 1641	2219 2344 2359	62.5	193
l'Etr-ATHLETIC-1	656 656 641	1562 1969 2000	3031 2953 2875	83.3	216
z'elr-AZALEA-1	438 500 516	2062 2125 2047	2844 2859 2828	116.9	180
b'Itr-BITTERSWEET-1	438 406 422	1766 1703 1781	2438 2453 2406	55.2	184
w'itr-BITTERSWEET-1	375 359 297	2391 2543 2552	2813 2984 3000	104.9	184
d'idr-CANDIED-1	297 328 328	2328 2391 2344	2844 2875 2797	73.3	163
s'Elr-CELEBRATION-1	609 578 578	1484 1375 1297	2625 2516 2500	84.7	200
r'eSr-CELEBRATION-1	500 469 484	1876 2141 2187	2266 2410 2552	85.4	168
l'esr-COMPLACENT-1	609 547 438	1687 1969 2190	2516 2688 2781	111.0	211
s'ilr-CONCEAL-1	359 359 453	2429 2359 2094	2813 2828 2797	117.9	174
d'ISr-CONDITION-1	391 391 391	2250 2219 2234	2859 2906 2857	77.8	198
r'Itr-CRITICISM-1	484 484 484	1750 1750 1750	2281 2328 2422	34.7	250
s'Izr-CRITICISM-1	391 375 391	1752 1714 1724	2667 2648 2648	74.8	174
r'Asr-CRUSTACEAN-1	547 516 391	1656 1609 1750	2187 2250 2594	63.3	168
t'eSr-CRUSTACEAN-1	531 516 500	2187 2219 2250	2781 2844 2859	102.9	180
k'Asr-CUSTOMARILY-1	484 531 469	1766 1797 1752	2281 2359 2495	82.2	258
d'ikr-DECREASE-1	375 359 359	2469 2648 2724	2984 3010 3076	87.4	222
r'isr-DECREASE-1	406 375 391	2152 2266 2312	2486 2703 2797	100.1	198
d'Elr-DELTA-1	531 609 641	1672 1656 1500	2828 2828 2838	74.9	168
d'Etr-DETRIMENT-1	531 562 500	1937 1812 1687	2813 2688 2500	86.2	174
d'Etr-DETRIMENTAL-1	562 547 547	1859 1766 1687	2563 2406 2381	82.6	188
d'Ilr-DILIGENTLY-1	422 484 500	1719 1531 1484	2734 2734 2766	76.4	190
d'Isr-DISCIPLINE-1	422 438 438	1703 1703 1687	2703 2672 2648	62.9	178
d'Isr-DISOBEDIENCE-1	391 391 359	1984 1953 1875	2813 2828 2828	54.9	174
b'idr-DISOBEDIENCE-1	375 375 359	2476 2581 2578	2891 2971 2933	79.4	186
w'edr-DISSUADED-1	500 500 484	1500 2078 2203	2672 2703 2766	105.5	178
b'etr-EXACERBATED-1	469 476 438	2048 2172 2297	2547 2752 2859	98.6	165
t'igr-FATIGUE-1	391 359 312	2790 2771 2762	3359 3343 3333	199.6	182
b'Asr-FILIBUSTER-1	625 625 641	1484 1531 1562	2422 2375 2406	89.8	165
g'izr-FOGEYS-1	328 344 359	2676 2688 2516	2952 3016 2938	156.6	182
r'Asr-FRUSTRATING-1	625 625 625	1547 1625 1656	2187 2312 2438	59.5	165
r'etr-FRUSTRATING-1	547 547 547	1953 2062 2125	2381 2467 2495	76.7	172
w'Azr-FUZZY-WUZZY-1	500 562 453	1438 1687 1719	2547 2594 2625	106.0	163
g'etr-GATOR-1	375 406 391	2469 2344 2344	2766 2797 2766	117.4	180
g'izr-GEEZERS-1	328 344 344	2734 2656 2563	3467 3200 3063	131.5	174
g'Atr-GUTTURAL-1	547 656 641	1812 1687 1609	2406 2250 2219	88.4	178
l'Asr-ILLUSTRIOUS-1	516 531 500	1391 1531 1594	2781 2703 2484	111.6	174
r'Edr-INCREDIBLY-1	594 578 562	1578 1609 1672	2172 2266 2344	58.5	200

d'isr-INDECENTLY-1	375 375 375	2516 2641 2547	2984 3047 3000	98.4	208
d'Asr-INDUSTRIAL-1	547 594 531	1750 1656 1687	2531 2453 2438	97.0	182
d'Asr-INDUSTRIALIZATION-1	594 641 484	1859 1719 1695	2563 2438 2500	108.6	229
z'eSr-INDUSTRIALIZATION-1	438 438 391	2062 2250 2328	2766 2875 2844	138.3	190
w'Izr-INQUISITIVE-1	422 422 391	1547 1687 1719	2641 2688 2625	81.0	208
s'Alr-INSULT-1	453 531 531	1297 1281 1250	2563 2516 2469	71.6	211
t'Egr-INTEGRITY-1	422 562 453	2062 2125 2156	2641 2594 2619	61.7	195
l'izr-ISOSCELES-1	438 406 375	1484 2047 2203	2813 2828 2813	126.7	165
J'ewr-JAYWALKING-1	453 406 375	2312 2391 2359	2703 2641 2688	128.8	158
d'ezr-LACKADAISICAL-1	422 469 453	2266 2203 2047	2797 2828 2790	100.9	186
l'EJr-LEGISLATOR-1	516 500 484	1531 1562 1734	2984 3000 2969	69.6	254
l'etr-LEGISLATOR-1	562 547 516	1547 1719 1937	2922 2844 2688	112.5	193
l'Itr-LITERATURE-1	500 516 500	1656 1812 1812	2813 2766 2734	71.3	176
l'Itr-LITIGATION-1	453 453 453	1638 1969 2172	2797 2766 2750	76.1	186
g'eSr-LITIGATION-1	391 422 406	2469 2453 2438	2922 2922 2922	132.3	178
b'idr-LOBBIED-1	422 438 422	2219 2328 2250	2914 2953 2922	40.1	232
l'itr-OBSOLETE-1	375 344 344	2375 2766 2672	2859 3086 3200	169.6	168
l'eSr-POPULATION-1	484 500 469	1766 2094 2125	2891 2922 2891	99.0	168
r'Ezr-PRESERVATION-1	547 422 359	1719 1750 1672	2625 2719 2719	73.0	198
t'Ekr-PROTECTION-1	562 578 531	1922 1891 2078	2400 2375 2391	76.3	200
w'izr-QUEASINESS-1	406 375 375	1797 2406 2406	2656 2781 2891	114.3	195
w'Esr-QUESTION-1	500 578 484	1375 1797 1838	2375 2453 2609	94.0	254
w'Esr-QUESTIONNAIRE-1	531 531 552	1406 1562 1734	2312 2375 2476	89.5	172
r'edr-RADIO-1	484 469 391	2187 2297 2344	2524 2790 2875	73.6	176
b'Atr-REBUTTAL-1	578 625 625	1484 1516 1578	2438 2438 2453	121.7	168
k'Itr-SCHIZOID-1	391 406 406	2266 2172 2109	2750 2766 2688	41.7	203
k'Itr-SCHIZOPHRENIC-1	406 391 391	2172 2125 1969	2641 2594 2531	37.7	203
s'iwr-SEAWEED-1	359 391 375	2484 2641 2406	3016 3109 2828	124.9	205
w'idr-SEAWEED-1	344 343 343	2312 2486 2495	2733 2790 2952	102.5	195
s'Igr-SIGNATURES-1	375 391 375	2078 2094 2094	2752 2703 2688	42.0	195
g'Etr-SPAGHETTI-1	406 500 516	2406 2297 2281	2857 2819 2714	94.1	180
t'etr-STATEHOUSE-1	516 516 500	2281 2359 2375	2844 2906 2906	112.8	172
t'Idr-TIDBIT-1	375 422 406	2281 2312 2234	2844 2844 2828	51.7	211
b'Itr-TIDBIT-1	469 469 438	2171 2152 1886	2563 2676 2629	93.9	174
r'izr-UNREASONABLE-1	438 438 406	2114 2250 2250	2352 2828 2859	108.0	174
w'Izr-VENTRILOQUISM-1	422 469 453	1344 1531 1641	2484 2516 2625	72.9	165
b'etr-VERBATIM-1	500 438 438	2297 2359 2406	2859 2875 2938	124.6	182
d'ets-ACCOMMODATED-1	422 391 344	2312 2359 2312	2875 2969 2922	122.5	158
l'ets-ACCUMULATED-1	531 531 500	1641 1906 2234	2953 2938 2922	129.5	180
g'ets-ALLIGATOR-1	422 469 484	2375 2234 2109	2714 2625 2563	87.4	163
b'Ets-ALPHABET-1	594 594 547	1844 1875 1838	2766 2813 2771	91.0	157
b'Ets-ALPHABETICAL-1	484 594 619	1719 1857 1922	2563 2562 2600	56.5	158
r'Iss-ARISTOCRATIC-1	469 484 484	1743 1766 1828	2257 2438 2547	52.0	167
l'Ets-ATHLETIC-1	531 609 625	1719 1797 1857	2875 2875 2859	68.7	160
b'Its-BITTERSWEET-1	469 484 469	2000 1969 1984	2656 2641 2656	50.2	172
w'its-BITTERSWEET-1	328 297 297	2600 2703 2719	2886 3114 3229	131.6	152
d'ids-CANDIED-1	328 344 328	2547 2578 2563	2906 2906 2859	75.1	158
s'Els-CELEBRATION-1	641 625 625	1531 1438 1328	2638 2610 2610	58.4	178
r'eSs-CELEBRATION-1	578 578 531	1687 1781 1800	2162 2267 2297	67.9	213
l'ess-COMPLACENT-1	516 500 500	1734 2203 2281	2625 2750 2797	108.5	172
r'Its-CRITICISM-1	391 484 469	1800 1867 1905	2171 2257 2381	49.0	168
s'Izs-CRITICISM-1	359 344 328	1750 1750 1734	2743 2703 2750	63.0	162
r'Ass-CRUSTACEAN-1	516 500 484	1578 1609 1656	2203 2219 2422	64.1	167
t'eSs-CRUSTACEAN-1	484 453 469	2078 2125 2162	2609 2688 2688	107.3	165

k'Ass-CUSTOMARILY-1	438 419 400	1981 1867 1838	2800 2733 2629	62.9	193
d'iks-DECREASE-1	344 328 281	2552 2667 2829	2971 2971 3029	86.2	162
r'iss-DECREASE-1	328 328 312	2250 2328 2297	2672 2734 2781	72.5	160
d'Els-DELTA-1	531 531 562	1781 1719 1609	2703 2734 2672	67.4	174
d'Ets-DETRIMENT-1	500 531 500	1859 1844 1848	2656 2734 2750	76.6	184
d'Ets-DETRIMENTAL-1	516 516 484	1914 1875 1812	2590 2562 2547	79.0	168
d'Iss-DISCIPLINE-1	438 422 422	1590 1547 1578	2719 2895 2981	39.0	151
w'eds-DISSUADED-1	484 500 484	1438 1703 2067	2505 2667 2867	110.2	172
t'igs-FATIGUE-1	328 312 328	2688 2672 2703	3266 3238 3210	139.4	158
b'Ass-FILIBUSTER-1	594 578 578	1484 1547 1562	2484 2531 2516	91.7	151
r'Ass-FRUSTRATING-1	594 625 667	1419 1467 1648	1797 2010 2371	84.8	174
r'ets-FRUSTRATING-1	500 484 453	1876 2152 2281	2328 2514 2719	118.3	163
w'Azs-FUZZY-WUZZY-1	484 484 484	1422 1641 1687	2743 2719 2750	113.8	168
g'ets-GATOR-1	359 391 422	2469 2476 2484	3067 3086 2971	98.6	163
d'iss-INDECENTLY-1	312 328 328	2563 2610 2563	2829 2875 2922	82.2	160
d'Ass-INDUSTRIAL-1	562 562 609	1828 1750 1703	2609 2547 2563	94.7	157
d'Ass-INDUSTRIALIZATION-1	469 516 516	1844 1734 1719	2629 2619 2590	87.4	172
z'eSs-INDUSTRIALIZATION-1	453 453 344	1875 1937 1953	2578 2563 2578	117.0	162
w'Izs-INQUISITIVE-1	422 453 406	1375 1734 1766	2571 2594 2719	104.0	172
s'Als-INSULT-1	500 594 562	1156 1063 1031	2594 2562 2590	93.2	155
t'Egs-INTEGRITY-1	562 562 547	1953 1969 2047	2734 2719 2641	71.1	205
l'izs-ISOSCELES-1	391 344 344	1359 1969 2187	2875 2875 2813	141.0	152
J'ews-JAYWALKING-1	438 500 500	2266 2250 2203	2657 2656 2638	128.0	172
d'ezs-LACKADAISICAL-1	406 406 391	2156 2156 2031	2688 2734 2672	115.9	155
l'EJs-LEGISLATOR-1	469 500 500	1547 1703 1703	2688 2656 2656	64.6	172
l'ets-LEGISLATOR-1	438 516 406	1766 1781 1875	2625 2625 2594	73.5	163
l'Its-LITERATURE-1	500 484 469	1672 1705 1734	2505 2324 2238	67.7	148
l'Its-LITIGATION-1	438 406 406	1828 1922 2000	2750 2750 2703	63.3	155
g'eSs-LITIGATION-1	453 469 406	2250 2250 2297	2828 2859 2828	151.4	147
l'its-OBSOLETE-1	344 312 328	2375 2657 2810	2938 3076 3095	149.5	152
l'eSs-POPULATION-1	484 531 469	1766 2016 2125	2734 2781 2766	122.0	144
r'Ezs-PRESERVATION-1	531 516 453	1625 1625 1656	2266 2578 2672	77.8	180
t'Eks-PROTECTION-1	562 531 547	1838 1886 1952	2352 2400 2438	36.1	172
w'izs-QUEASINESS-1	328 312 312	1891 2352 2295	2688 2734 2766	128.7	155
w'Ess-QUESTION-1	578 609 578	1562 1703 1781	2524 2533 2453	64.3	165
w'Ess-QUESTIONNAIRE-1	516 547 453	1578 1734 1797	2581 2533 2625	79.8	160
r'eds-RADIO-1	375 328 328	2250 2344 2359	2724 2844 2875	66.2	158
b'Ats-REBUTTAL-1	594 578 578	1391 1344 1328	2438 2516 2514	102.2	200
k'Its-SCHIZOID-1	375 391 391	2248 2248 1952	2600 2657 2552	41.4	193
k'Its-SCHIZOPHRENIC-1	406 406 422	2031 2000 1875	2656 2656 2641	36.4	174
s'iws-SEAWEED-1	359 344 344	2638 2648 2486	2952 2924 2838	64.3	172
w'ids-SEAWEED-1	312 312 297	2429 2562 2590	2766 2859 2790	85.2	154
s'Igs-SIGNATURES-1	344 375 359	1969 1953 1937	2625 2594 2563	30.4	168
g'Ets-SPAGHETTI-1	422 422 422	2328 2266 2234	2844 2859 2828	70.0	155
t'ets-STATEHOUSE-1	484 484 500	2266 2328 2297	2875 2938 2906	122.3	168
t'Ids-TIDBIT-1	406 391 359	2031 2062 2000	2859 2875 2797	49.0	190
b'Its-TIDBIT-1	391 375 359	1875 1953 1906	2734 2766 2813	44.5	182
w'Izs-VENTRILOQUISM-1	500 484 469	1562 1594 1609	2484 2391 2422	77.4	176
b'ets-VERBATIM-1	484 484 484	2203 2362 2438	2891 2969 2953	139.4	168

C.4 Speaker MP (Male)

Label	F1 (Hz)	F2 (Hz)	F3 (Hz)	Du. (ms)	F0 (Hz)
b'Izc-ABYSMAL-1	438 422 375	1703 1750 1687	2531 2656 2719	101.9	152
d'etc-ACCOMMODATED-1	453 453 453	2000 2031 1984	2563 2531 2484	104.2	152
l'etc-ACCUMULATED-1	500 484 469	1343 1562 1800	2422 2469 2438	80.7	158
d'Alc-ADULTERATED-1	516 562 625	1438 1257 1125	2250 2203 2219	48.1	151
r'etc-ADULTERATED-1	453 453 438	1638 1838 1969	1969 2095 2276	70.5	151
g'etc-ALLIGATOR-1	422 438 453	2156 2078 2094	2516 2453 2422	101.3	151
b'Etc-ALPHABET-1	500 562 547	1578 1594 1562	2281 2391 2422	104.5	155
b'Etc-ALPHABETICAL-1	453 500 484	1531 1562 1547	2266 2422 2422	60.9	139
w'etc-ANTIQUATED-1	469 469 453	1406 1766 1937	2141 2187 2203	76.0	158
t'Ekc-ARCHITECTURE-1	500 562 547	1625 1657 1657	2391 2203 2109	73.1	155
r'Isc-ARISTOCRATIC-1	438 438 422	1344 1552 1703	1771 1990 2453	52.0	144
l'Etc-ATHLETIC-1	609 609 594	1250 1344 1438	2312 2391 2422	71.5	155
z'elc-AZALEA-1	422 438 453	1781 1828 1594	2547 2484 2438	83.7	147
b'Itc-BITTERSWEET-1	422 453 453	1891 1859 1781	2469 2453 2453	71.8	154
w'itc-BITTERSWEET-1	328 328 328	1797 1943 2016	2094 2133 2187	40.0	162
d'idc-CANDIED-1	375 359 344	2094 2141 2156	2686 2743 2733	89.2	152
s'Elc-CELEBRATION-1	531 531 562	1469 1276 1141	2375 2328 2344	46.0	160
r'eSc-CELEBRATION-1	469 453 438	1562 1781 1981	1829 2076 2267	91.6	148
l'esc-COMPLACENT-1	500 453 438	1500 2016 2078	2305 2391 2469	77.0	154
s'ilc-CONCEAL-1	328 312 375	2109 2187 2031	2484 2531 2419	131.0	155
d'ISc-CONDITION-1	422 438 438	1953 1922 1984	2594 2469 2438	85.0	145
r'Itc-CRITICISM-1	469 469 438	1375 1422 1562	1705 1790 1971	43.5	162
s'Izc-CRITICISM-1	344 328 359	1547 1562 1516	2547 2578 2641	65.0	168
r'Asc-CRUSTACEAN-1	469 453 453	1343 1484 1719	1667 1819 2105	49.0	136
t'eSc-CRUSTACEAN-1	469 469 438	1953 2078 2078	2375 2422 2438	108.3	160
k'Asc-CUSTOMARILY-1	594 578 547	1406 1344 1391	2141 2203 2281	62.5	144
d'ikc-DECREASE-1	359 359 344	2094 2156 2297	2734 2688 2656	91.3	150
r'isc-DECREASE-1	391 359 328	1752 2000 2094	2124 2200 2578	83.3	165
d'Elc-DELTA-1	453 578 625	1781 1391 1203	2375 2187 2281	66.8	147
d'Etc-DETRIMENT-1	453 531 531	1790 1686 1714	2324 2312 2312	70.9	155
d'Etc-DETRIMENTAL-1	453 516 531	1844 1734 1695	2438 2391 2352	81.8	144
d'Ilc-DILIGENTLY-1	438 469 484	1875 1641 1375	2406 2422 2438	43.0	154
d'Isc-DISCIPLINE-1	422 453 422	1906 1867 1703	2500 2578 2625	63.3	167
d'Isc-DISOBEDIENCE-1	438 453 422	1937 2000 1656	2531 2547 2641	75.3	151
b'idc-DISOBEDIENCE-1	391 391 359	1922 2047 2141	2359 2469 2609	59.3	143
w'edc-DISSUADED-1	438 438 438	1531 1914 2000	2250 2248 2248	114.5	148
b'etc-EXACERBATED-1	438 438 438	1969 2094 2094	2344 2391 2453	105.0	150
t'igc-FATIGUE-1	328 328 344	2248 2203 2187	2891 2781 2641	148.8	155
b'Asc-FILIBUSTER-1	547 656 641	1125 1200 1359	2187 2312 2391	100.2	152
g'izc-FOGEYS-1	312 312 312	2266 2203 2156	2594 2578 2578	135.7	152
r'Asc-FRUSTRATING-1	578 562 514	1250 1234 1238	1752 1984 2141	80.2	158
r'etc-FRUSTRATING-1	469 453 453	1419 1514 1657	1895 2019 2143	69.5	155
w'Azc-FUZZY-WUZZY-1	562 547 453	1188 1312 1375	2094 2297 2406	67.1	150
g'etc-GATOR-1	406 406 406	2156 2152 2172	2495 2500 2457	116.7	137
g'izc-GEEZERS-1	312 312 328	2266 2281 2125	3019 2771 2581	129.5	158
g'Atc-GUTTURAL-1	562 609 594	1234 1250 1281	2031 1875 1876	68.1	140
l'Asc-ILLUSTRIOUS-1	594 578 547	1094 1219 1375	2359 2297 2344	73.1	157
r'Edc-INCREDIBLY-1	531 531 531	1188 1297 1375	1819 1819 1810	66.4	151
d'isc-INDECENTLY-1	344 328 312	2156 2187 2172	2657 2686 2686	94.0	154
d'Asc-INDUSTRIAL-1	484 578 562	1495 1495 1486	2234 2219 2344	96.4	154

d'Asc-INDUSTRIALIZATION-1	469 531 531	1562 1438 1419	2062 2078 2281	82.1	157
z'eSc-INDUSTRIALIZATION-1	453 453 438	1812 1984 2016	4500 3469 2328	116.6	151
w'Izc-INQUISITIVE-1	484 453 406	1438 1790 1771	2234 2469 2656	62.8	163
s'Alc-INSULT-1	562 594 625	1038 1031 1031	2406 2422 2422	39.7	178
t'Egc-INTEGRITY-1	516 484 438	1829 1819 1905	2375 2190 2210	72.8	160
l'izc-ISOSCELES-1	406 312 328	1906 2250 2078	2438 2410 2429	102.0	148
J'ewc-JAYWALKING-1	438 453 438	1937 2016 2031	2219 2297 2312	104.1	148
d'ezc-LACKADAISICAL-1	406 422 422	2000 2141 2047	2547 2563 2531	133.2	142
l'EJc-LEGISLATOR-1	516 516 438	1297 1500 1705	2375 2312 2297	62.0	140
l'etc-LEGISLATOR-1	531 484 438	1295 1672 1703	2219 2406 2359	67.2	148
l'Itc-LITERATURE-1	453 453 453	1375 1375 1391	2422 2406 2391	34.5	154
l'Itc-LITIGATION-1	469 469 453	1391 1391 1484	2344 2422 2438	43.5	155
g'eSc-LITIGATION-1	438 453 453	2250 2109 2156	2505 2469 2469	124.5	154
b'idc-LOBBIED-1	344 297 312	2094 2187 2187	2371 2552 2638	108.8	148
l'itc-OBSOLETE-1	422 328 328	1922 2172 2187	2578 2410 2359	102.0	151
l'eSc-POPULATION-1	484 422 375	1594 1969 2047	2438 2422 2438	119.1	147
r'Ezc-PRESERVATION-1	469 438 422	1250 1219 1375	1781 2016 2406	44.8	143
t'Ekc-PROTECTION-1	500 594 578	1625 1571 1657	2297 2250 2172	78.6	154
w'izc-QUEASINESS-1	328 312 312	2143 2203 2181	2328 2419 2457	74.0	154
w'Esc-QUESTION-1	562 547 453	1219 1297 1516	2078 2219 2375	72.0	148
w'Esc-QUESTIONNAIRE-1	562 547 547	1276 1362 1484	2109 2156 2344	60.0	148
r'edc-RADIO-1	469 438 438	1469 1703 1895	1619 1937 2067	94.0	145
b'Atc-REBUTTAL-1	594 625 609	1219 1234 1234	2031 2187 2086	91.5	140
k'Itc-SCHIZOID-1	375 422 422	1875 1797 1656	2406 2438 2438	54.1	165
k'Itc-SCHIZOPHRENIC-1	406 453 453	1906 1766 1656	2297 2281 2344	49.4	160
s'iwc-SEAWEED-1	344 344 312	2062 2187 2238	2609 2563 2390	70.0	160
w'idc-SEAWEED-1	359 328 328	1891 2062 2141	2297 2328 2422	111.0	155
s'Igc-SIGNATURES-1	453 453 406	1672 1891 2000	2469 2453 2422	58.5	160
g'Etc-SPAGHETTI-1	438 484 531	2078 1969 2016	2429 2406 2371	92.0	144
t'etc-STATEHOUSE-1	469 469 453	1969 2062 2125	2516 2516 2484	103.0	157
t'Idc-TIDBIT-1	406 422 406	2000 1984 1953	2578 2578 2656	51.1	162
b'Itc-TIDBIT-1	438 453 438	1828 1859 1828	2344 2469 2563	100.5	157
r'izc-UNREASONABLE-1	344 359 359	2000 2047 1891	2286 2516 2547	67.0	152
w'Izc-VENTRILOQUISM-1	516 484 438	1422 1500 1562	2187 2333 2484	68.2	167
b'etc-VERBATIM-1	422 438 438	1906 2000 2016	2484 2453 2609	112.4	144
b'Izr-ABYSMAL-1	344 359 375	1672 1656 1578	2505 2578 2547	83.4	130
d'etr-ACCOMMODATED-1	297 312 328	1937 2062 1953	2563 2547 2486	111.0	120
l'etr-ACCUMULATED-1	484 438 406	1531 1656 1703	2250 2328 2344	48.1	151
d'Alr-ADULTERATED-1	391 594 625	1203 1109 1063	2125 2000 2078	56.3	126
r'etr-ADULTERATED-1	422 406 391	1590 1687 1812	1924 2067 2162	55.0	114
g'etr-ALLIGATOR-1	375 375 406	2038 2010 1971	2476 2390 2328	81.0	124
b'Etr-ALPHABET-1	484 531 484	1469 1562 1641	2125 2156 2187	81.0	123
b'Etr-ALPHABETICAL-1	484 453 438	1562 1531 1500	2125 2172 2172	69.1	122
w'etr-ANTIQUATED-1	422 406 391	1922 1969 1953	2281 2391 2453	80.4	120
t'Ekr-ARCHITECTURE-1	578 609 594	1719 1719 1733	2344 2281 2257	75.7	124
r'Isr-ARISTOCRATIC-1	359 406 438	1188 1453 1578	1609 1848 2234	63.3	143
l'Etr-ATHLETIC-1	609 688 625	1281 1438 1547	2516 2469 2469	64.1	182
z'elr-AZALEA-1	375 391 500	1922 1906 1641	2438 2469 2375	90.7	140
b'Itr-BITTERSWEET-1	328 391 359	1848 1829 1829	2324 2343 2371	39.6	174
w'itr-BITTERSWEET-1	328 328 328	1672 1962 2095	2286 2324 2457	56.5	122
d'idr-CANDIED-1	297 297 281	2016 2062 2109	2531 2469 2371	70.0	113
s'Elr-CELEBRATION-1	533 531 578	1266 1156 1109	2094 2109 2000	42.1	148
r'eSr-CELEBRATION-1	438 438 391	1286 1476 1686	1686 1857 2048	103.7	122
l'esr-COMPLACENT-1	484 359 312	1438 1656 1922	2343 2400 2453	82.2	124

s'ilr-CONCEAL-1	250 406 469	2105 1750 1594	2391 2410 2391	75.1	160
d'ISr-CONDITION-1	375 375 375	1937 1922 2000	2516 2516 2531	83.4	128
r'Itr-CRITICISM-1	438 469 453	1422 1516 1531	1752 1922 1969	24.4	246
s'Izr-CRITICISM-1	281 328 312	1516 1531 1500	2641 2641 2625	55.7	180
r'Asr-CRUSTACEAN-1	188 328 312	1406 1500 1656	1781 1924 2095	55.5	116
t'eSr-CRUSTACEAN-1	375 375 344	1984 2062 2016	2516 2594 2625	103.9	130
k'Asr-CUSTOMARILY-1	533 688 609	1453 1406 1375	2352 2429 2453	76.6	180
d'ikr-DECREASE-1	391 375 375	1672 1719 1687	2390 2438 2391	62.9	132
r'isr-DECREASE-1	266 234 266	2086 2133 2143	2467 2562 2600	76.4	133
d'Elr-DELTA-1	371 476 495	1719 1429 1266	2286 2229 2297	69.7	130
d'Etr-DETRIMENT-1	438 516 547	1750 1641 1625	2328 2312 2438	87.5	151
d'Etr-DETRIMENTAL-1	371 562 453	1686 1578 1547	2109 2038 2047	75.0	126
d'Ilr-DILIGENTLY-1	344 438 469	1484 1406 1328	2109 2141 2141	51.0	160
d'Isr-DISCIPLINE-1	344 438 375	1672 1578 1562	2406 2484 2531	61.7	147
d'Isr-DISOBEDIENCE-1	391 391 375	1797 1703 1703	2571 2609 2638	62.3	137
b'idr-DISOBEDIENCE-1	344 344 328	2125 2219 2257	2422 2484 2552	92.2	123
w'edr-DISSUADED-1	391 406 391	1750 1848 1933	2219 2305 2362	67.2	134
b'etr-EXACERBATED-1	406 375 359	1984 2031 2000	2371 2533 2533	90.9	131
t'igr-FATIGUE-1	297 312 281	2125 2141 2210	2733 2688 2641	127.5	147
b'Asr-FILIBUSTER-1	625 672 641	1219 1219 1328	2156 2125 2162	86.2	124
g'izr-FOGEYS-1	312 312 312	2219 2203 2141	2453 2531 2500	108.3	119
r'Asr-FRUSTRATING-1	547 625 500	1400 1457 1476	1829 1952 2105	83.0	132
r'etr-FRUSTRATING-1	484 453 438	1495 1514 1590	1752 1810 1876	41.3	107
w'Azr-FUZZY-WUZZY-1	344 344 438	1250 1297 1344	1969 2047 2172	62.0	113
g'etr-GATOR-1	375 406 406	2171 2141 2038	2533 2571 2533	106.5	138
g'izr-GEEZERS-1	297 281 328	2250 2286 2187	2594 2547 2594	128.0	128
g'Atr-GUTTURAL-1	562 531 609	1453 1438 1469	2109 2156 2141	86.0	131
l'Asr-ILLUSTRIOUS-1	641 609 562	1141 1250 1234	2203 2257 2295	75.0	147
r'Edr-INCREDIBLY-1	453 453 438	1457 1514 1514	1800 1848 1886	32.0	154
d'isr-INDECENTLY-1	297 297 297	2094 2109 2109	2500 2578 2563	85.6	160
d'Asr-INDUSTRIAL-1	547 578 641	1516 1484 1469	2171 2229 2333	87.5	122
d'Asr-INDUSTRIALIZATION-1	516 625 656	1500 1422 1453	2295 2305 2500	91.4	132
z'eSr-INDUSTRIALIZATION-1	359 344 344	1797 1922 2031	2500 2531 2547	110.0	128
w'Izr-INQUISITIVE-1	391 344 297	1547 1594 1609	2419 2543 2641	56.2	178
s'Alr-INSULT-1	625 578 476	1086 1000 905	2257 2229 2171	91.0	143
t'Egr-INTEGRITY-1	500 469 453	1844 1750 1828	2391 2305 2276	62.2	154
l'izr-ISOSCELES-1	297 297 281	1422 1922 2000	2297 2638 2781	100.1	121
J'ewr-JAYWALKING-1	375 406 375	1906 1953 2062	2234 2295 2297	95.0	126
d'ezr-LACKADAISICAL-1	359 375 375	1952 1906 1891	2469 2563 2484	97.6	127
l'EJr-LEGISLATOR-1	453 516 469	990 1422 1719	2406 2422 2375	92.0	174
l'etr-LEGISLATOR-1	500 438 438	1453 1562 1750	2359 2333 2324	94.5	125
l'Itr-LITERATURE-1	406 406 391	1203 1469 1562	2200 2281 2297	63.5	129
l'Itr-LITIGATION-1	375 391 359	1328 1391 1406	2266 2266 2203	60.0	142
g'eSr-LITIGATION-1	422 453 422	2094 2016 2141	4125 2516 2656	151.3	155
b'idr-LOBBIED-1	328 359 359	1703 1875 1953	2328 2438 2563	38.0	154
l'itr-OBSOLETE-1	359 344 297	1828 2000 2078	2406 2438 2438	77.0	129
l'eSr-POPULATION-1	333 359 375	1453 1750 1906	2352 2438 2438	63.0	119
r'Ezr-PRESERVATION-1	448 453 438	1305 1438 1514	1594 1848 1981	72.7	147
t'Ekr-PROTECTION-1	619 609 547	1667 1703 1705	2250 2162 2057	76.0	124
w'izr-QUEASINESS-1	328 328 328	1953 2094 2078	2359 2422 2484	58.0	174
w'Esr-QUESTION-1	547 562 484	1406 1562 1625	1984 2250 2406	86.0	172
w'Esr-QUESTIONNAIRE-1	641 594 609	1484 1547 1516	1969 2094 2234	74.0	180
r'edr-RADIO-1	406 422 375	1469 1594 1750	1781 1984 2109	93.3	128
b'Atr-REBUTTAL-1	594 672 547	1281 1281 1406	2031 2048 2047	104.2	125

k'Itr-SCHIZOID-1	391 375 375	1828 1766 1672	2422 2438 2484	47.1	132
k'Itr-SCHIZOPHRENIC-1	438 406 391	1828 1766 1641	2312 2281 2248	41.9	128
s'iwr-SEAWEED-1	266 234 219	2297 2391 2333	2688 2688 2590	84.0	186
w'idr-SEAWEED-1	281 281 281	1984 2094 2094	2359 2359 2375	74.6	117
s'Igr-SIGNATURES-1	344 328 312	1656 1719 1750	2406 2281 2234	51.3	186
g'Etr-SPAGHETTI-1	295 375 352	2152 1953 1733	2552 2419 2276	90.0	122
t'etr-STATEHOUSE-1	484 484 375	1937 2019 2078	2375 2324 2295	104.4	167
t'Idr-TIDBIT-1	234 297 328	2200 2016 1906	2505 2563 2531	37.0	172
b'Itr-TIDBIT-1	375 422 391	1797 1719 1656	2281 2391 2422	82.0	128
r'izr-UNREASONABLE-1	391 375 375	1752 1933 1952	1971 2190 2429	90.5	143
w'Izr-VENTRILOQUISM-1	453 438 406	1362 1590 1609	2141 2219 2578	51.0	145
b'etr-VERBATIM-1	406 422 406	1984 2094 2078	2531 2578 2578	115.6	139
d'Λls-ADULTERATED-1	516 578 562	1172 1094 1078	2124 2172 2234	43.6	122
r'ets-ADULTERATED-1	359 344 328	1486 1609 1687	1733 1922 1953	46.0	117
g'ets-ALLIGATOR-1	375 406 406	2105 2047 1922	2438 2476 2422	134.3	117
l'Ets-ATHLETIC-1	641 641 625	1422 1484 1500	2438 2375 2406	80.0	148
z'els-AZALEA-1	359 391 469	1875 1875 1594	2516 2547 2484	93.3	129
b'Its-BITTERSWEET-1	297 375 359	1812 1766 1714	2281 2297 2267	55.9	124
w'its-BITTERSWEET-1	250 250 297	1859 2010 2143	2281 2312 2328	67.3	152
d'ids-CANDIED-1	328 297 281	2125 2171 2190	2469 2406 2422	95.1	121
s'Els-CELEBRATION-1	516 625 688	1375 1250 1156	2109 2219 2219	57.3	143
r'eSs-CELEBRATION-1	484 422 391	1531 1762 1875	1891 2067 2156	104.7	121
r'Λss-CRUSTACEAN-1	344 328 266	1438 1453 1676	1686 1750 2010	69.5	120
t'eSs-CRUSTACEAN-1	406 422 391	1859 1984 2078	2578 2578 2571	120.1	145
d'Els-DELTA-1	406 578 609	1641 1469 1190	2281 2297 2203	72.6	130
d'Ets-DETRIMENTAL-1	484 609 609	1766 1672 1547	2266 2229 2266	86.6	126
t'igs-FATIGUE-1	312 344 344	2109 2125 2172	2734 2719 2563	210.9	134
b'Λss-FILIBUSTER-1	594 625 609	1172 1297 1406	2062 2047 2152	86.6	122
r'Λss-FRUSTRATING-1	656 625 688	1257 1297 1375	1733 1859 2010	50.8	122
r'ets-FRUSTRATING-1	391 375 328	1484 1578 1705	1733 1891 2047	78.0	120
w'Λzs-FUZZY-WUZZY-1	609 641 516	1141 1250 1422	2000 2031 2181	107.5	121
g'ets-GATOR-1	391 406 406	2141 2094 2109	2516 2516 2578	116.9	132
d'Λss-INDUSTRIAL-1	547 688 656	1484 1438 1344	1943 2125 2248	111.5	142
d'Λss-INDUSTRIALIZATION-1	438 594 578	1625 1391 1375	2234 2210 2344	107.9	125
z'eSs-INDUSTRIALIZATION-1	406 391 344	1719 2016 2125	2391 2672 2609	147.9	123
w'Izs-INQUISITIVE-1	484 453 438	1312 1469 1531	2344 2438 2531	71.1	176
s'Λls-INSULT-1	594 641 672	1029 962 914	2238 2250 2141	90.5	124
l'izs-ISOSCELES-1	328 328 297	1594 1828 1859	2328 2359 2344	105.5	121
J'ews-JAYWALKING-1	391 500 484	1844 1859 1922	2219 2266 2250	114.0	128
l'EJs-LEGISLATOR-1	422 469 406	1391 1469 1609	2187 2141 2125	83.5	121
l'ets-LEGISLATOR-1	516 469 375	1484 1625 1766	2344 2359 2297	63.3	122
l'Its-LITERATURE-1	406 422 391	1328 1516 1531	2219 2234 2234	74.2	134
l'Its-LITIGATION-1	406 391 375	1203 1422 1562	2469 2406 2344	61.5	139
g'eSs-LITIGATION-1	422 453 438	2109 2031 2109	2448 2457 2484	158.0	145
l'eSs-POPULATION-1	486 410 343	1375 1703 1962	2359 2390 2375	113.0	198
r'Ezs-PRESERVATION-1	453 406 391	1328 1344 1406	1734 1937 2162	50.0	122
w'izs-QUEASINESS-1	312 312 312	1969 2141 2109	2312 2406 2516	100.8	123
w'Ess-QUESTION-1	531 562 547	1531 1609 1625	2094 2281 2281	65.0	115
w'Ess-QUESTIONNAIRE-1	641 609 594	1266 1391 1422	1906 1969 2016	98.0	129
r'eds-RADIO-1	406 406 406	1891 1984 2067	2187 2276 2371	74.7	140
k'Its-SCHIZOID-1	375 359 312	1922 1859 1750	2391 2359 2438	53.7	126
k'Its-SCHIZOPHRENIC-1	422 438 438	1781 1750 1672	2469 2453 2484	41.9	162
s'Igs-SIGNATURES-1	375 406 391	1781 1859 1859	2391 2391 2375	36.3	154
g'Ets-SPAGHETTI-1	406 547 594	2062 1859 1734	2344 2219 2200	100.5	133

t'ets-STATEHOUSE-1	453 422 359	1922 2062 2031	2422 2469 2500	110.0	127
t'Ids-TIDBIT-1	312 344 359	2031 2031 2000	2410 2516 2547	32.2	157
b'Its-TIDBIT-1	391 391 375	1734 1719 1703	2324 2371 2390	78.0	134
w'Izs-VENTRILOQUISM-1	422 422 359	1328 1391 1531	2086 2219 2362	79.0	129
b'ets-VERBATIM-1	344 359 344	1891 2016 2078	2343 2344 2352	145.4	122

Appendix D

Additional Tables of Mean F1-F2 Midpoints

The following tables show values of mean F1-F2 midpoints as plotted in Chapter 3 and Appendix B.

Table D.1: Means for F1 and F2 midpoints and number of tokens for all vowels in database, all speakers, as plotted in Figure 3.1. Each cell lists, from top to bottom, number of tokens, F1 in Bark, F2 in Bark.

	/i/	/ɪ/	/e/	/ɛ/	/ʌ/
JS	170 3.10 13.33	167 4.05 12.00	220 4.12 12.88	162 5.11 11.52	135 5.50 10.54
RU	45 3.84 14.20	48 4.64 12.43	61 5.29 13.60	45 5.98 12.17	34 5.88 10.89
EE	45 3.56 14.60	50 4.31 12.41	62 4.64 13.47	46 5.29 12.20	33 5.47 11.21
MP	39 3.35 13.19	46 4.18 11.71	59 4.26 12.48	41 5.25 11.10	32 5.56 10.06

Table D.2: Means for F1 and F2 midpoints for /hVd/ vowels for all speakers of the present study (which were not considered part of the database), as plotted in Figure 3.1. There were two tokens of each /hVd/ vowel for each speaker. Peterson and Barney (1952) data, marked P&B, are also shown. Each cell lists, in order, F1 in Bark, F2 in Bark.

	/i/	/ɪ/	/e/	/ɛ/	/ʌ/
JS	2.86 13.45	4.34 12.95	4.27 13.23	5.48 12.30	6.10 10.71
RU	3.84 14.89	5.35 13.38	5.09 14.46	5.92 13.16	5.79 11.67
EE	3.55 15.38	4.27 13.89	3.91 14.77	5.48 13.38	5.61 12.07
MP	3.17 14.07	4.27 13.03	4.55 13.42	5.54 12.22	5.35 10.50
P&B (female)	3.22 15.14	4.35 14.34	- -	5.86 13.92	6.97 10.57
P&B (male)	2.83 13.80	3.98 12.86	- -	5.21 12.34	6.09 9.56

Table D.3: Means for F1 and F2 midpoints for speaker JS, as plotted in Figures 3.8 through 3.11. Each cell shows, in order, F1 in Bark, F2 in Bark.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	3.13	3.99	3.98	5.29	5.50
		13.48	11.93	13.04	11.47	10.41
	sec.	3.15	4.12	4.21	5.03	5.65
		13.35	11.88	12.88	11.34	10.62
context	b-init.	3.23	4.02	4.06	5.34	5.84
		13.29	12.35	12.96	11.75	9.92
	d-init.	2.81	3.69	4.03	5.02	5.44
		13.64	12.15	13.19	12.05	11.20
	g-init.	3.06	3.95	3.84	-	5.81
		13.52	12.70	13.35	-	11.12
	g-fin.	-	-	-	4.77	-
		-	-	-	12.50	-
	w-init.	3.04	4.03	3.99	5.28	-
		13.34	11.24	12.76	10.79	-
	r-init.	3.17	4.18	4.22	4.86	5.31
		13.21	11.45	12.57	11.27	10.65
	l-init.	3.21	4.31	4.31	-	-
		13.31	11.61	12.78	-	-
	l-fin.	-	-	-	5.46	5.38
		-	-	-	10.54	10.04
style	nons.	2.91	3.96	4.02	5.00	5.50
		13.27	11.98	12.87	11.80	10.66
	car.ph.	2.83	3.93	3.86	5.09	5.41
		13.43	11.96	12.98	11.41	10.43
	read	3.30	4.11	4.21	5.13	5.64
		13.35	11.92	12.93	11.49	10.49
style	read	3.16	4.17	4.17	5.11	5.49
		13.45	12.09	13.02	11.33	10.52
(read-sp.)	spont.	3.31	4.21	4.24	5.17	5.30
		13.06	12.11	12.70	11.41	10.66

Table D.4: Means for F1 and F2 midpoints for speaker RU, as plotted in Figures B.1 and B.2. Each cell shows, in order, F1 in Bark, F2 in Bark.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	3.73 14.29	4.55 12.41	5.29 13.70	6.08 12.02	6.09 10.73
	sec.	3.99 14.03	4.83 12.29	5.25 13.61	5.88 12.23	5.69 11.19
context	b-init.	4.02 14.30	4.60 13.01	5.28 13.71	6.09 12.11	6.21 10.11
	d-init.	3.77 13.95	4.45 12.57	5.23 14.14	5.78 12.82	5.92 11.70
	g-init.	3.62 14.85	4.62 13.11	5.19 14.42	- -	6.00 11.30
	g-fin.	- -	- -	- -	6.04 13.07	- -
	w-init.	4.02 14.23	4.75 11.96	5.37 13.03	6.02 11.84	- -
	r-init.	3.77 13.95	4.59 11.92	5.33 13.54	5.78 12.15	5.33 11.79
	l-init.	3.99 13.68	5.13 11.53	5.21 13.06	- -	- -
	l-fin.	- -	- -	- -	6.17 10.77	5.97 9.92
style	car.ph.	3.81 14.35	4.66 12.30	5.24 13.56	5.78 12.21	5.68 10.93
	read	3.88 14.08	4.77 12.31	5.33 13.68	6.13 12.16	6.07 10.91
style	car.ph.	3.77 14.40	4.62 12.42	5.30 13.68	5.79 12.17	5.71 10.89
	read	3.89 14.09	4.78 12.53	5.19 13.75	6.12 12.10	6.02 10.92
(read-sp.)	spont.	3.84 14.10	4.61 12.31	5.34 13.45	6.05 12.05	5.89 10.83

Table D.5: Means for F1 and F2 midpoints for speaker EE as plotted in Figures B.3 and B.4. Each cell shows, in order, F1 in Bark, F2 in Bark.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	3.67	4.36	4.46	5.39	5.71
		14.61	12.26	13.82	12.19	11.01
	sec.	3.53	4.35	4.54	5.11	5.46
		14.50	12.45	13.25	12.01	11.30
context	b-init.	3.84	4.27	4.46	5.48	6.04
		14.61	12.96	13.84	12.52	10.92
	d-init.	3.47	4.02	4.20	5.25	5.63
		14.66	12.24	14.01	12.30	11.86
	g-init.	3.51	4.10	4.31	-	5.79
		14.96	13.43	14.23	-	12.21
	g-fin.	-	-	-	4.84	-
		-	-	-	12.91	-
	w-init.	3.32	4.38	4.62	5.32	-
		14.67	11.57	12.86	11.71	-
	r-init.	3.80	4.55	4.64	4.97	5.40
		13.93	11.90	13.57	11.89	11.34
	l-init.	3.66	4.82	4.78	-	-
		14.51	12.01	12.69	-	-
	l-fin.	-	-	-	5.64	5.06
		-	-	-	11.28	9.47
style	car.ph.	3.45	4.34	4.32	5.08	5.47
		14.94	12.31	13.72	12.25	11.14
	read	3.82	4.41	4.75	5.44	5.61
		14.33	12.36	13.36	12.18	11.29
style	car.ph.	3.37	4.37	4.46	5.07	5.51
		15.01	12.36	13.71	12.24	11.20
	read	3.75	4.37	4.76	5.40	5.64
		14.40	12.47	13.52	12.17	11.42
(read-sp.)	spont.	3.36	4.32	4.69	5.36	5.28
		14.43	12.39	13.29	12.19	11.19

Table D.6: Means for F1 and F2 midpoints for speaker MP as plotted in Figures B.5 and B.6. Each cell shows, in order, F1 in Bark, F2 in Bark.

		/i/	/ɪ/	/e/	/ɛ/	/ʌ/
stress	prim.	3.45 13.32	4.27 11.53	4.21 12.63	5.03 11.15	5.73 10.20
	sec.	3.24 13.20	4.38 11.56	4.29 12.37	5.26 10.91	5.51 10.08
context	b-init.	3.58 13.15	4.20 11.99	4.24 13.08	5.05 11.28	6.22 9.78
	d-init.	3.32 13.30	4.38 12.13	3.98 13.01	5.22 11.66	5.60 10.84
	g-init.	3.17 13.66	4.20 12.10	4.13 13.21	- -	5.78 10.38
	g-fin.	- -	- -	- -	5.21 11.96	- -
	w-init.	3.25 13.26	4.33 11.49	4.34 12.46	5.48 10.74	- -
	r-init.	3.43 12.99	4.48 10.94	4.45 11.35	4.69 10.40	4.85 10.64
	l-init.	3.32 13.17	4.34 10.60	4.37 11.90	- -	- -
	l-fin.	- -	- -	- -	5.20 10.15	5.64 9.06
style	car.ph.	3.44 13.40	4.55 11.73	4.47 12.61	5.21 11.02	5.56 10.04
	read	3.25 13.14	4.08 11.39	4.04 12.43	5.11 11.22	5.50 10.18
style	car.ph.	3.40 13.37	4.54 11.86	4.50 12.60	5.20 10.75	5.46 10.10
	read	3.25 13.01	3.88 11.74	4.17 12.33	5.18 10.98	5.27 10.11
(read-sp.)	spont.	3.18 13.07	4.07 11.70	4.18 12.47	5.45 11.00	5.67 9.93